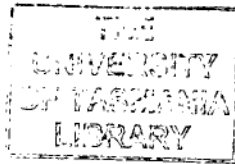


# **Ecology of the threatened herb *Brunonia australis* in Tasmania**



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Submitted in fulfilment of the requirements for the degree of  
Master of Science

School of Plant Science  
University of Tasmania  
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## **Declaration of Originality**

To the best of my knowledge and belief the material included in this thesis is original except where duly acknowledged in the text. No part of this work has been previously submitted or accepted, by any institution, for the award of any other degree or diploma.

Signed:

CRAIG H. HAWKINS

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## Abstract

This thesis investigates major factors influencing the ecology of the threatened species *Brunonia australis* in Tasmania. *Brunonia* is listed as vulnerable under Tasmanian Threatened Species legislation, being restricted to depleted forest communities in the central north of the state. At the commencement of this study in 1998, the species was very poorly reserved and threatened by land clearing, inappropriate grazing regimes and logging. Existing information about the response of *Brunonia* to various management impacts was limited to anecdotal observations.

Five main areas of investigation were undertaken: 1) Known populations were surveyed to validate conservation status and determine habitat requirements, 2) Reproductive characteristics were examined to improve understanding of population dynamics, 3) Effects of grazing by domestic stock were examined in a 2 year trial in a typical population, 4) Impacts of selective logging and three silvicultural techniques in a typical forest type were assessed, 5) Success of eucalypt regeneration in relation to the silvicultural treatments is reported.

58 populations were identified in the study, 35 more than previously reported. Most occurred in Inland *Eucalyptus amygdalina* forest. More than half contained less than 1000 plants, but several had more than 100,000 plants. The species could be downgraded from vulnerable to rare under Tasmanian threatened species guidelines, but should not be delisted due to continuing threats.

*Brunonia* has an efficient reproductive capacity. Flowering was profuse in sunny situations and pollination effected by common insect vectors. Germination was found to occur readily (80%) without any apparent dormancy mechanisms. Several findings are reported for the first time including *Brunonia*'s poor dispersal capability and inability to store seed in the soil.

Season of grazing influenced *Brunonia* populations. Winter grazing significantly benefited populations compared to grazing in other seasons. Winter grazing reduced understorey competition during *Brunonia*'s dormant period but direct grazing of plants during summer reduced reproductive ability. Understorey competition restricted germination and reduced survival of adult plants in ungrazed plots.

Selective logging benefited *Brunonia* in the first year after logging, except in heavily scarified plots. After three years, the recovery of *Brunonia* was significantly poorer in burnt and scarified areas compared to logged-only areas and controls. The increase in understorey density in logged areas, including wattle and bracken in the burnt areas reduced the survival of *Brunonia* and restricted recruitment.

In contrast, eucalypt regeneration was most successful following the logging/scarification treatment (84% plots stocked), compared to logging/burning (77%) and logging only (57%) treatments. The logging only treatment produced unacceptable regeneration rates in terms of the adopted Tasmanian stocking standard (65% of plots stocked). Browsing by native and introduced animals influenced the success of regeneration.

Moderate disturbance is important in most populations. Lack of appropriate disturbance allows more competitive understorey species to eventually inhibit the growth and establishment of *Brunonia*.

Various management techniques are proposed.



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# 1: Introduction

## 1.1 Background to thesis

*Brunonia australis* Smith ex. R.Br.

is an attractive herb found in all Australian states and mainland territories. In Tasmania, the species is restricted to dry forests in the central north of the state. These forests have been extensively cleared for agriculture and more



**Figure1.1:** *Brunonia australis* (photo: Wendy Potts)

recently forestry and disturbed by fire, sheep and cattle grazing, firewood cutting and logging (Fensham 1989). Due to these ongoing threats to its habitat and because populations are generally small and fragmented, *Brunonia* was listed as 'Vulnerable' in the Tasmanian *Threatened Species Protection Act (1995)*.

Following the implementation of the *Threatened Species Protection Act (1995)* there was greater interest in the impacts of logging on *Brunonia* due to the number of applications to disturb it in proposed logging coupes in northern Tasmania. To determine whether logging and associated silvicultural practices had a significant impact on the species a case study, the impetus of this thesis, was set up in an inland *Eucalyptus amygdalina* forest near Bracknell, Tasmania, scheduled for selective logging in 1998.

The status of *Brunonia* populations across Tasmania is largely unknown and a listing statement, which presents the case for its inclusion in the *Threatened Species Protection Act (1995)*, had not been prepared at the commencement of this study. Furthermore, the literature reveals no detailed work on the ecology of the species, particularly in Tasmania. An understanding of *Brunonia*'s ecological requirements is critical for analysing its' responses to logging, so further studies were

instigated on its distribution and habitat requirements, reproductive ecology and responses to grazing.

Most populations of *Brunonia* in Tasmania, including the logging study site, have been grazed - mainly by sheep. The removal of livestock for several years from the regenerating logged forest may mask the direct impacts of logging. A grazing trial was established in a forest similar to that used for the logging study, in order to examine the impacts of grazing restriction and season of grazing.

Partial logging followed by some form of seedbed preparation such as scarification or low intensity burning is typically employed in the dry forests across *Brunonia*'s range. Clearfelling, burning and resowing was a more common practice in the earlier days of woodchipping in the 1970s and 1980s but is rarely used now in these forests (Hickey and Wilkinson 1999). The silvicultural success of partial logging practices, specifically in *Eucalyptus amygdalina* forests on Tertiary alluvial soils, has received limited attention although similar forest types have been studied (Hickey and Wilkinson 1999). As an adjunct to the main thrust of the research of this thesis, the success of eucalypt regeneration after different silvicultural practices has also been reported due to the concomitant aims of logging achieving both adequate conservation of threatened species like *Brunonia* and acceptable levels of eucalypt regeneration for long term maintenance of forest cover and productivity.

## **1.2 Disturbance in the habitat range of *Brunonia* in Tasmania**

Disturbance is an important process in many ecosystems (Pickett and White 1985). It can be broadly defined as 'an event that removes organisms and opens up space which can be colonized by the same or different species' (Begon *et al.* 1996). Disturbance may provide open areas allowing improved light availability and space for the recruitment of new individuals from seed and reduce the cover of competing species (Begon *et al.* 1996). A discussion on the immensely complex array of plant responses to disturbance is not warranted here but it is relevant to acknowledge the importance of disturbance in the dry eucalypt forests of Tasmania where *Brunonia* is found.

Heavy impacts such as clearing and gravel extraction or constant disturbance such as persistent grazing with domestic livestock has been shown to be detrimental to many of the understorey species in these forest types (Fensham and Kirkpatrick 1989, Yates and Hobbs 1997). However, periodic disturbance is important for the maintenance of many species, including rare and threatened species, in Tasmanian dry eucalypt forests and other similar Australian ecosystems (Fensham and Kirkpatrick 1989, Gilfedder and Kirkpatrick 1994, McIntyre 1995, Morgan 1998). Potts (1997) reported the importance of regular fire and ground disturbance for the persistence of some threatened *Euphrasia* species in Tasmania and Gilfedder and Kirkpatrick (1994) have demonstrated the importance of grazing for survival of the threatened daisy *Leucochrysum albicans*. Pyrke (1994) found that animal diggings might enhance the germination or establishment of some dry sclerophyll understorey species in Tasmania. However, *Brunonia*, which was one of the species studied, did not appear to be reliant on such disturbances. In broader terms, Fensham and Kirkpatrick (1989) recommend regular burning and/or grazing of lowland dry sclerophyll forests in Tasmania in order to maintain species richness but there are no easily defined guidelines that cover all situations (Kirkpatrick 1999).

Little is known of the response of *Brunonia* to disturbance. Heavy grazing, soil scarification and weed invasion have been reported as being detrimental (Kirkpatrick and Gilfedder 1999, Tasmanian Government 1996b) but roading and general disturbance were noted in the Tasmanian Regional Forest Agreement (RFA) as having positive effects (Tasmanian Government 1996b). The RFA also listed the species as persisting in selectively logged areas but acknowledged the lack of scientific data. The species therefore appeared to have a level of tolerance to certain disturbances but its responses were largely unknown prior to the commencement of this study. A better understanding of the ability of *Brunonia* to respond to disturbance was a major thrust of this research.

### **1.3 Summary of areas addressed by thesis**

In summary the principle areas addressed by this work are:

1. The current realized and potential distribution of *Brunonia* in Tasmania.

2. The main habitat requirements of *Brunonia* in Tasmania and an analysis of the main factors influencing known populations.
3. Appropriate conservation status of *Brunonia* in Tasmania under both State and International guidelines.
4. The main elements of *Brunonia*'s reproductive ecology including, flowering phenology, pollination requirements, seed production capability, seed dispersal, persistence of seed in the soil and seed germination requirements.
5. The effect of sheep grazing on *Brunonia*..
6. The effect of partial logging with or without silvicultural practices such as scarification or post harvesting burning on *Brunonia*.
7. Appropriate silvicultural practices for eucalypt regeneration in inland *Eucalyptus amygdalina* forests.

#### **1.4 Structure of thesis**

The thesis has been compiled as a set of five self-standing scientific papers ready for submission to appropriate refereed journals (with some appropriate formatting changes for thesis presentation). A separate introduction and concluding discussion of findings and management recommendations draws the papers together.

Additional work and relevant data compiled during the preparation of the thesis and of benefit to the general understanding of *Brunonia* in Tasmania are included as appendices but are not necessarily referred to in the papers. These include a listing statement as submitted to the Tasmanian Government and population maps based on collected GPS points.

## **2. The Distribution, habitat requirements and conservation status of *Brunonia australis* in Tasmania**

Craig Hawkins, Rob Wiltshire and Mike Peterson

**Abstract** *Brunonia australis* is a threatened herb in Tasmania due to a limited distribution in remnant dry forests in the north of the state, poor representation in reserves, and continuing threatening processes such as land clearing and grazing. Despite listing as a threatened species in Tasmania, little work has assessed factors affecting its conservation status or its potential distribution in the State. This study reviews the condition and habitat characteristics of known *Brunonia* populations in Tasmania. From a field survey in Nov.-Dec 2000, 58 populations were identified, 35 more than previously reported. Population size and condition were assessed and characteristics were recorded, including: geology, soils, elevation, forest communities, and associated species. Population size and condition was also assessed. *Brunonia* was found to be restricted to relatively flat, lowland dry forests (below 350m) on well-drained, geologically recent soils. Most populations consisted of less than 1000 plants. A TWINSpan analysis of associated species grouped *Brunonia* populations into three distinct communities: moist Inland *Eucalyptus amygdalina* forest, dry Inland *E. amygdalina* forest, and heathy *E. obliqua* / coastal *E. amygdalina* forest. Most *Brunonia* populations occurred in the two Inland *E. amygdalina* communities. Modeling of habitat characteristics using Arcview 3.2 GIS surface models, demonstrated that the species is unlikely to be found outside its current known distribution in the central north of Tasmania but new populations could be found within this region. *Brunonia* may be downgraded from vulnerable to rare under Tasmanian threatened species guidelines due to the number of populations found. Appropriate disturbance regimes, particularly winter grazing, were found to be an important component of healthy populations and the need for careful application of disturbance to maintain *Brunonia* populations is discussed.



## 2.1 Introduction - *Brunonia australis* across Australia.

*Brunonia australis* (blue pincushion) is named after the famous botanist Robert Brown who sailed with Matthew Flinders and first discovered the plant in 1804 at Arthur's Seat, Port Phillip, Victoria. It is a small herb that has striking sky blue, or sometimes, mauve flowers which are tightly clustered on 2-3cm terminal heads on 30-40cm long scapes. Its common name derives from the pollen-laden indusiums which make the inflorescence look like a pincushion stuck with yellow-headed pins. Some have argued against the placement of the species in the monotypic family Brunoniaceae (Carolin 1977), including the species in the Goodeniaceae due to the presence of the stylar indusium.

*Brunonia* is amongst the most widely distributed native plants in Australia. The species ranges from the dry forests of central north Tasmania, through the deserts of central Australia, to the Kimberley Region of Western Australia and central Queensland (Fig. 2.1).

Hnatiuk (1990) shows that *Brunonia* occurs across northern, central and southeastern South Australia. Table 2.1 summarizes the recorded habitats of



**Figure 2.1:** Distribution of *Brunonia australis* based on National and State herbarium records (except the South Australian Herbarium) and all known populations in Tasmania.

*Brunonia* from the various herbaria. *Brunonia* is largely found in open habitats mainly in, but not restricted to, drier parts of the continent. Soils are typically sands, gravelly or stony, but rarely with high clay content. Red sands or other red soils are frequently mentioned in all states, but yellow sands, quartzite sands, granitic soils and mudstone soils are also mentioned. Populations in Victoria have been reported on heavier soils than in other states (Ewart 1930, Cochrane *et al.* 1973). Underlying geology is variable but includes basalt, dolerite, ironstone, mudstone, granite, alluvium and Aeolian sands.



*Brunonia* is recognized as a threatened species only in Tasmania (TSPA 1995), with 23 known populations in 1996 (Tasmanian Government 1996b) but has also been reported as declining in some parts of Western Australia due to over grazing by domestic livestock (Gardner 1972). Threatening processes identified as contributing to a decline in *Brunonia* in Tasmania include: forest clearing, grazing by domestic stock and other animals, *Phytophthora* infection, scarification and fertilizer addition (Tasmanian Government 1996b). Small populations of *Brunonia* may decline further as a result of its self-incompatibility system (Peacock and Smith-White 1977).

Clearing and inappropriate grazing regimes in the dry grassy forests of the northern midlands have had the biggest influence on *Brunonia* populations in the past (Fensham 1989, Fensham and Kirkpatrick 1989), including relatively recent times (Kirkpatrick 1991). Clearing for urban development and hobby farms around Launceston has had a significant impact on a core area of the distribution. In remnant patches throughout the urban area, weed invasion and restriction of disturbance regimes such as grazing and fire have continued to cause population decline due to increased understorey competition.

Disturbance in dry eucalypt forests and woodlands has an important role in the maintenance of herbaceous species like *Brunonia* (Fensham and Kirkpatrick 1989, Gilfedder and Kirkpatrick 1994, McIntyre 1995, Morgan 1998). Without regular disturbance, more competitive perennial understorey species, including grasses, shrubs and other higher strata species, begin to dominate native herbs which struggle to compete for resources like sunlight, moisture and nutrients, and opportunities for flowering and germination are substantially diminished (Clarke 2000). In contrast, disturbance that is too heavy, or too regular, may also be detrimental to herbaceous species through direct destruction of plants, introduction of competitive weed species, or constant interruption of reproduction (McIntyre *et al.* 1995, Yates and Hobbs 1997). The influence of disturbance (or lack of disturbance) on the current condition of Tasmanian *Brunonia* populations was examined and was an important component of assessing its conservation status. The factors currently influencing the condition of *Brunonia australis* populations in Tasmania and the main habitat characteristics for the species in the State have also been reported. Habitat information was used to model the potential distribution of

*Brunonia*. An assessment of conservation status was also conducted using Tasmanian Government guidelines and a listing statement prepared.

**Table 2.1:** Major vegetation types across Australia containing *Brunonia australis*, a summary of herbarium and literature records, and observations of the author (Tas).

State	Habitat / Vegetation association
NSW, NT, QLD, SA, WA	Mulga ( <i>Acacia aneura</i> ) and other <i>Acacia</i> woodlands (e.g. <i>A. catenulata</i> –QLD, <i>Acacia acuminata</i> -WA).
NT, WA, QLD	Spinifex ( <i>Triodia</i> spp.) dominated sandplains and dunes
NSW	Grassy <i>Eucalyptus</i> woodlands (e.g. <i>E. blakelyi</i> / <i>E. melliodora</i> / <i>E. macrorhyncha</i> , <i>E. populnea</i> , <i>E. melanophloia</i> , <i>E. macrorhyncha</i> / <i>E. dives</i> )
NSW	Mallee woodlands (e.g. <i>E. dwyeri</i> , <i>E. intertexta</i> , <i>E. morrisii</i> )
NT	<i>Melaleuca</i> shrublands
NT	<i>Plectrachne</i> spp. grasslands
NT	Mallee woodlands (e.g. <i>E. gamophylla</i> )
QLD	<i>Eucalyptus</i> woodlands (e.g. <i>E. tenuipes</i> , <i>E. populnea</i> / <i>Casuarina leuhmanii</i> )
QLD	Cypress pine ( <i>Callitris</i> ) woodland, <i>Casuarina</i> woodland ( <i>C. cristata</i> )
QLD	Low shrubland – <i>Themeda</i> grassland, grasslands
QLD	Heath
QLD	Closed palm forest (one record –160km SW of Longreach)
SA	Dry sclerophyll forest (e.g. <i>E. obliqua</i> )
SA	Mallee woodland (e.g. <i>E. gamophylla</i> , <i>E. justonii</i> , mallee and spinifex rocky hills)
TAS	Dry sclerophyll forest (e.g. <i>E. amygdalina</i> , <i>E. viminalis</i> , <i>E. obliqua</i> )
VIC	<i>Eucalyptus</i> woodlands (e.g. <i>E. goniocalyx</i> – <i>E. macrorhyncha</i> , <i>Eucalyptus</i> / <i>Callitris endlicheri</i> , <i>E. melliodora</i> / <i>E. microcarpa</i> / <i>E. sideroxylon</i> / <i>E. polyanthemos</i> / <i>E. blakelyi</i> , <i>E. tricarpa</i> )
VIC	Snow-gum woodland ( <i>E. pauciflora</i> ) (Foreman and Walsh 1993)
VIC	Dry sclerophyll forest (e.g. <i>E. sideroxylon</i> , <i>E. obliqua</i> , <i>E. obliqua</i> / <i>E. radiata</i> )
VIC	<i>Themeda</i> grassland
WA	Eucalypt woodlands (e.g. <i>E. melliodora</i> / <i>E. microcarpa</i> )
WA	Mallee woodlands (e.g. <i>E. loxophleba</i> , <i>E. gamophylla</i> , <i>E. leptopoda</i> , <i>E. justonii</i> )
WA	Other open woodlands (e.g. <i>Melaleuca fulgens</i> / <i>Casuarina</i> sp. (e.g. <i>Casuarina cristata</i> ) / <i>Acacia</i> sp.)

## 2.2 Method

### 2.2.1 Location and survey of populations in Tasmania

All available records of known *Brunonia* locations in Tasmania were obtained from the following sources:

Tasmanian herbarium records to 1999

The Tasmanian Parks and Wildlife Service GTSPOT database

Forestry Tasmania's CONSERVE database

The Department of Roads threatened flora database

Queen Victoria Museum records.

A literature search was conducted and revealed details on several populations. Other locations were identified during the course of the study by the author, Forest Practices Board botanists and Private Forest Reserve Program botanists. A range of other people from Bushcare, Launceston City Council and the public also reported populations. Spurious records in the Parks and Wildlife database and CONSERVE including all records south of Campbell Town, on the east coast or in the far northeast were ignored on the basis of lack of herbarium records and on the advice of botanists with the Threatened Species Unit (Dept. Primary Industry, Water and Environment).

Landowners were contacted for access permission and surveys were conducted from 16 November 2000 to 29 December 2000. Access was denied to one property in the Cressy / Longford area. Sites were first searched for *Brunonia* and the general extent of the population determined. In large areas of potential habitat a further 100-200 metres past the last observed plant were searched in a range of directions prior to estimating the approximate edge of the population.

A modified version of the Parks and Wildlife Service 'bushplot score sheet' was used to record details on the physical and botanical habitat in the vicinity of the population. Three 2x2 m plots were randomly located in the vicinity of the *Brunonia* population. All species present in a plot were recorded except grasses, which, due to time constraints and difficulties in grass identification were

given an overall cover score. An additional 15-20 minutes was taken to record other species not found in the plots. If *Brunonia* was not recorded after an extensive search of the area, general site details were recorded and no further analysis was undertaken. Forest communities were recorded as outlined by Duncan and Brown (1985). Species names were recorded as given in Buchanan (1995).

Five 10cm soil cores were collected across the area of *Brunonia* distribution at 51 populations. Soil samples were air-dried and analysed at the Cooperative Research Centre for Sustainable Production Forestry using the methods of Rayment and Higginson (1992). Samples were analysed for pH, available phosphorus (Colwell P), total phosphorus (P%), total nitrogen (N%) and total carbon (Walkley and Black C%). Part of the original sample was also used to determine texture as defined by Northcote (1984). Geology was determined from the Tasmanian Mines Department 1:50,000 geological map series. Soil analysis was not undertaken for 7 populations.

#### **2.2.2 Assessment of habitat characteristics**

Populations were defined under the criteria set out by the International Union for the Conservation of Nature (IUCN 1994) where patches less than 1km apart are treated as a single population. Where several distinct “patches” made up a population the dominant characteristic for the entire population was used in habitat descriptions (e.g. vegetation type). Summaries were made of the following features:

- Current known distribution
- Observed forest communities
- Geology
- Soil type (texture)
- Tenure of populations
- Environmental conditions (elevation, rainfall)
- Landform

### 2.2.3 Modeling

#### 2.2.3.1 TWINSpan communities.

A TWINSpan analysis (Hill 1979) of flora species recorded at all sites containing *Brunonia* was conducted using PCord 4.10 (MJM Software Design Oregon) to determine if there were definable *Brunonia* communities based on associated vegetation. The analysis was based on presence / absence of 168 species recorded at 74 *Brunonia* sites.

#### 2.2.3.2 Model of potential *Brunonia* habitat

Only locations with a verified occurrence of *Brunonia* were used for modeling distribution to ensure that factors relevant to the species influenced the distribution model. The model included all 74 sites (sub-populations) recorded in December 2000, covering 58 populations.

Key factors used in the modeling of *Brunonia* distribution were subjectively chosen based on a review of data collected during field surveys and that were available as Arcview 3.2a GIS layers (ESRI, Redlands, California). Representative grid references for populations were assigned and a range of values for each parameter were obtained from the Arcview surface models for those sites. The ranges were then used to model potential distribution by surface –layer intersection. Parameters and their values used for modeling were as follows:

- Vegetation – TASVEG (Tasmanian Government 2004).

Forest types included were:

- AC –*Eucalyptus amygdalina* coastal forest
- AI – Inland *E. amygdalina* forest
- AD - *E. amygdalina* forest on dolerite
- Eai - Inland *E. amygdalina* woodland
- Ead - *E. amygdalina* woodland on dolerite
- Ea - *E. amygdalina* woodland
- *E. obliqua* forest types were not used due to the low number of populations found within these types.

- Geology – 6 relevant types were included covering:
  - Tertiary geology (3)
  - Quaternary geology (1)
  - Jurassic geology
  - Permian geology (1).
- Other parameters used are summarized in table 2.2.

**Table 2.2:** Parameters and their ranges used for modeling *Brunonia* habitat in Tasmania.

Parameter	Range
1. Mean Annual Temperature (°C)	10-13
2. Elevation (m.a.s.l.)	9-339
3. Mean annual precipitation (mm)	610-1031
4. Slope (deg.)	0-11
5. Mean rainfall - driest month (mm)	35-49mm
6. Mean rainfall –driest quarter (mm)	113-163
7. Range wettest to driest month (mm)	29-88

Three models were produced using the following combinations of parameters:

Model 1 – TASVEG and Geology layers

Model 2 – Model 1 and variables 1-4 (Table 2.2)

Model 3 – Model 1 and variables 1-7 (Table 2.2)

#### 2.2.4 Assessment of conservation status

Each population was assigned a condition category using the following definitions:

1. Very healthy population, high numbers of plants (>10000) and lack of threatening processes such as increasing understorey competition, weeds or heavy disturbances - long term survival likely under current management practices.
2. Moderately healthy population but smaller numbers (<10000 plants) or lower densities - may be some contraction but longer term survival should continue under current management.
3. Struggling population - long term survival not assured under current conditions. (E.g. plants showing symptoms of poor health such as leaf discoloration, lack of flowering,

disease or excessive damage through heavy browsing or mechanical disturbance etc.

Also low numbers of plants (<5000)).

4. Very poor population or facing imminent major change-local extinction likely at some point in the next 10 years under current management. (Very low numbers of plants - <100s and ongoing threatening processes such as populations on roadside batters, small urban remnants, heavy all-year grazing regimes).
5. Previously recorded but not found

A summary of population condition was prepared and used to support assessment of conservation status. Formal assessment of conservation status was conducted using the database Threatened Species Unit (2004) a Tasmanian Government computer program. The assessment was based largely on collected population details including area of occupancy and estimated number of individuals. Several rule-sets are contained within the program but the one used for this analysis was based on the Tasmanian Threatened Species Protection Act guidelines (TSPA 1995), which is based largely on IUCN guidelines.

#### **2.2.5 Summary of historical and current threatening processes**

The historical and current threatening processes of all known populations in December 2001 were assessed. Historical impacts were deduced during field inspection and after discussion with landowners. Multiple threats may have been assigned to a population if applicable and threats were identified as affecting whole or part of the population. Threats to a part population meant that one distinct patch was subject to the threat but other patches not, such as for a population spread across several landowners or spatially separated. For the assessment of current threatening processes it was assumed that the current management intent would continue into the foreseeable future.

#### **2.2.6 Lodgement of specimens with the herbarium**

Specimens of *Brunonia* from locations without records in the Tasmanian Herbarium were collected under permit number FL99319, issued 19 April 2000, pressed and submitted to the herbarium.

## 2.3 Results and Discussion

### 2.3.1 Assessment of *Brunonia* habitat characteristics

#### 2.3.1.1 Current known distribution

A total of 58 *Brunonia* populations were recorded as at December 2001 (compared to the 23 known populations reported in 1996 - Tasmanian Government 1996b), within a land area of 3100km<sup>2</sup> of which the species was estimated to occupy only 79ha.

*Brunonia* was found from the Railton / Latrobe areas in the northwest, east to Deddington, and from Lefroy in the north to as far south as the Isis Valley at the approximate latitude of Campbell Town (Fig. 2.2). The majority of populations were found in the northern Midlands region, extending west from Launceston to Westwood, south to Blackwood Creek and east to Epping Forest. An isolated, southernmost location was found during the course of the study in the Isis Valley west of Campbell Town. This population was 70m higher in elevation than any other location. None of the populations in the northwest, from Beaconsfield to Latrobe contain large numbers of plants and possible reasons for this are discussed below. A pictorial record of representative populations, a detailed summary table and location maps of populations surveyed in 2000 are attached as appendices 1A, 1D and 1E, respectively. Table 2.3 provides a summary of confirmed *Brunonia* populations in Tasmania as at November 2004 and includes additional populations located after the analysis reported in this paper.

Tasmanian records of *Brunonia* were found in the following references: Peacock and Smith-White (1977), Kirkpatrick *et al.* (1988), Ratkowsky *et al.* (1993a, b, c), Shearing (1993), Ratkowsky and Ratkowsky (1994), Launceston City Council (1999). One reference in Peacock and Smith-White (1977) to a population at “Mt. Direction to East Arm” on the eastern side of the Tamar River was not located, nor were any in that general vicinity. A population at Windermere adjacent the East Tamar Highway appears to be extinct leaving a 32km gap in the East Tamar region between known populations at Launceston and Lefroy.



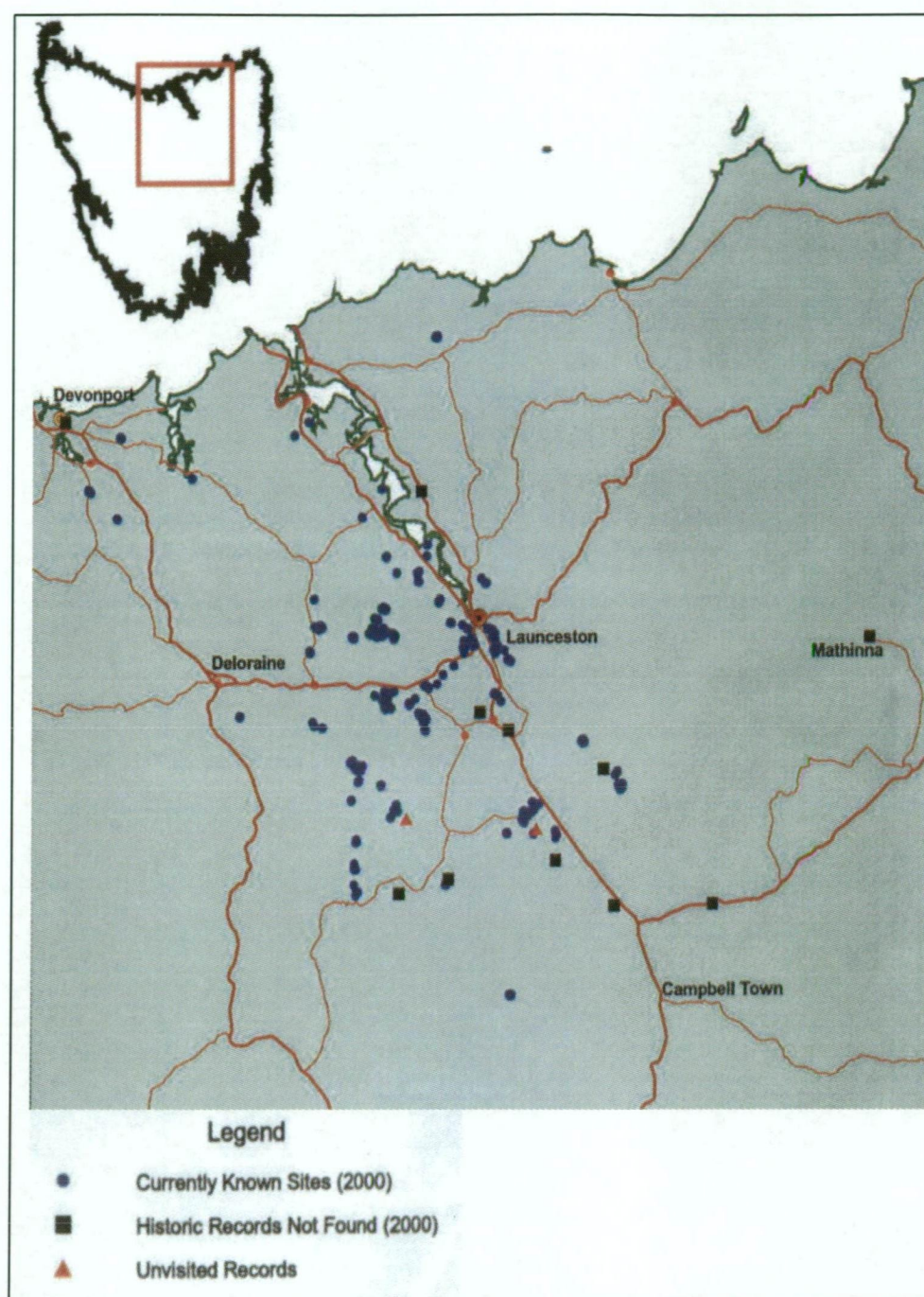


Figure 2.2: The known distribution of *Brunonia australis* in Tasmania in 2000.

**Table 2.3:** Details of Tasmanian *Brunonia* populations and component patches confirmed between Dec. 2000 and Nov. 2004. (Forest types after Duncan and Brown (1985), GrAm = grassy *E. amygdalina*, HeAm = heathy *E. amygdalina*, ShAm = shrubby *E. amygdalina*, SilObl = Siliceous *E. obliqua*, ArgObl = Argillaceous *E. obliqua*, Allo = *Allocasuarina* forest).

Population Summary				Patch Summary				
No.	Name	Area (ha)	No. of plants	Name	Forest type	Area (ha)	No. of plants	Dec. 2000 survey?
1	Glen Stuart	25	100000		GrAm			y
2	Franklin Rivulet	0.25	300	Franklin Rivulet	HeAm			y
3	Beaconsfield	0.001	3	Bowens Jetty Rd	HeAm			y
4	Holwell Rd	0.5	300		HeAm			y
5	Powranna	161	780000	Powranna rd west	GrAm	45	200000	y
				Powranna Rd SW		40	10000	y
				Smithfield	GrAm	30	60000	y
				Emu Plains	GrAm	6.5	10000	y
				Powranna central	GrAm	40	500000	y
				Powranna east	GrAm	0.25	5	y
6	Lake River Rd	1.6	500	Bayles	GrAm	1.5	400	y
				Bayles rdside	GrAm	0.1	100	n
10	Devon Hills	0.4	250	Devon Hills Hwy	GrAm	0.1	200	y
				Summit Dve	(GrAm)	0.25	25	y
				Loutitt's -D. Hills	GrAm	0.05	30	n
14	Lefroy	8	200000	Lefroy nth	SilObl			y
16	Pateena Rd	2	800					
17	Prospect	5	5750	Kate Reed	GrAm	2	2200	y
				Ingamellis	GrAm	0.1	250	y
				Willow Crt	GrAm	2	3000	y
				Havelock St	GrAm	1	500	y
18	Prospect Vale	3	25500	Cheltenham Way	GrAm	2.5	25000	y
				Casino golf links	GrAm	0.5	500	n
19	Youngtown	6	7000	Youngtown park	GrAm	4	5000	y
				Blue Gum Park	GrAm	1.2	2000	y
				Miami park	GrAm	0.8	60	y
20	Norwood	28	151000	Punchbowl east 1 (grassy)	GrAm	2.5	30000	y
				Punchbowl east 2	GrAm	2.5	20000	y
				punchbowl west	GrAm	1.5	500	y
				Carr Villa	GrAm	20	100000	y
				Hawthorne St	GrAm	1.4	1000	y
21	Biralee	?	?					n
23	Elphinstone Road	14	50000	"Elphinstone"	GrAm	14	50000	y
				Elphinstone sth	GrAm	0.1	2	n
24	Bishopsbourne nth	68	113000	Sherwood nth	GrAm	25	3000	y
				Sherwood sth		33	60000	y
				Woodstock nth	GrAm	10	50000	y
25	Bishopsbourne	5	5000	woodstock south	GrAm			n
26	Riverside	5	15000		GrAm			y
27	Ecclestone Rd	10	10000		GrAm			y

Population Summary				Patch Summary				
No.	Name	Area (ha)	No. of plants	Name	Forest type	Area (ha)	No. of plants	Dec. 2000 survey?
28	Westwood nth	1	100		GrAm			y
29	Westwood	145	171000	B Archer west	GrAm	10	18000	y
				B Archer east	GrAm	15	3000	y
				Viney east	GrAm	19	100000	y
				Viney west		100	50000	n
30	Relbia	2	250	Grant Staples	GrAm	1.5	200	y
				Lapham	GrAm	0.5	50	y
31	Glenwood Road	0.05	100		GrAm			n
32	Bass Hwy Hadspen	0.25	100		GrAm			n
33	Bass Hwy Carrick	0.25	200		cleared			n
34	Mt Joy	13	50000		GrAm			y
35	Bracknell	3.5	1000		GrAm			y
36	Bracknell north	52	45500	Cresswell	GrAm	3	25	y
				Spencer Cpt B	GrAm	10	20000	y
				Spencer Cpt F	GrAm	10	15000	y
				Spencer Cpt A	GrAm	11	5000	n
				Spencer Cpt C	GrAm	8	3000	n
				Spencer Cpt D	GrAm	4	500	n
				Spencer Cpt E	GrAm	6	2000	n
37	Bracknell east	1	500		GrAm			y
38	Carrick south	10	8000		GrAm			y
39	Carrick East	20	100000		GrAm			y
40	Carrick west	65	266000	Walker	GrAm	28	200000	y
				Quamby Plains E	GrAm	2.5	8000	y
				Quamby Plains W	GrAm	1	5	n
				Heazlewood N	GrAm	14	8000	y
				Heazlewood S	GrAm	20	50000	n
41	Trevallyn	1	200		GrAm			y
42	Gorge	0.01	1	Gorge	Allo	0.01	1	y
		1	500	Cambridge St	GrAm	1	500	y
44	Long Plains	2	40		ShAm			y
45	Bridgenorth	0.25	4		ShAm			y
47	Native Plains	0.5	300		ShAm			y
48	Henry Somerset	10	2000		ArgObl			y
49	Moriarty	4	600		SilObl			y
50	Quamby Brook	1	1500		ArgObl			y
51	Poatina	1	210	Webley B	GrAm	1	200	y
				Webley A	(GrAm)	0.01	10	y
52	Blackwood Ck nth	2	500		GrAm			y
53	Blackwood Ck sth			Bhill A Ckline	GrAm	1.2	600	y
				Bhill A Plntn	(GrAm)	1	100	y
54	Mountain Vale	1.4	200		GrAm			y
55	Exeter	1	40		HeAm	1	40	y

Population Summary				Patch Summary				
No.	Name	Area (ha)	No. of plants	Name	Forest type	Area (ha)	No. of plants	Dec. 2000 survey?
56	Gravelly Beach	0.25	50		ShAm			n
57	Brushy Rivulet	4	3000		GrAm			y
58	Selbourne East	14	55000		GrAm			y
59	Selbourne	7.1	4630	Rdside	GrAm	3	4000	y
				sth	GrAm	4	600	n
				rdside west	GrAm	0.1	30	n
60	Beach Rd	0.5	600		GrAm	0.5	600	y
61	Legana	0.5	100		GrAm	0.5	100	y
					GrAm	0.05	5	n
62	Epping Forest	5	10000		GrAm			n
63	Danbury sth	1.5	200		GrAm			y
64	Danbury nth	2.5	1000		GrAm			y
65	Deddington nth	0.5	20		GrAm	0.5	20	n
66	Deddington sth	66	500000		GrAm			y
67	Isis Valley	5.5	1500		GrAm			y
68	Cluan	0.25	16		GrAm			n
85	South Esk							n
86	Beauty Point	1	3000	Byrne 1	GrAm	0.05	20	n
				Byrne 2	GrAm	0.001	4	n
				Oxford street	GrAm	1	3000	n
87	Flowery Gully T/O	0.001	20		GrAm			n
88	Tamar Ridge Winery	0.05	10		GrAm			n
89	Walkem Exeter	2	5000		ArgObl		5000	n
90	Launceston Tip	2.5	6000		GrAm	2.5	6000	n
91	Connorville	1	50		GrAm			n
92	Yorktown historic site	1	30		HeAm			n

It was difficult to determine the number of recorded populations that have become extinct due to the number of erroneous records in databases but table 2.4 provides a summary of past records where the species could not be found in 2000. The exact locations of some reliable Tasmanian Herbarium records could not be determined due to insufficient information but gave important historical range information covering areas such as Mathinna, East Devonport, Cleveland, Liffey and Railton. The records suggest the range has contracted in the east, southeast and northwest. No populations were found in forests surrounding Mathinna despite over 5 hours of searching during peak flowering time, in several areas of likely habitat.

**Table 2.4:** Previously recorded locations where *Brunonia* was not found in 2000

Record source: – 1. Tas. herbarium, 2. GTSPOT (Parks and Wildlife Service), 3. Conserve (Forestry Tas.), 4. Dept of Roads database, 5. Other Wildlife Service record. Reliability: - 1. reliable, 2. unreliable.

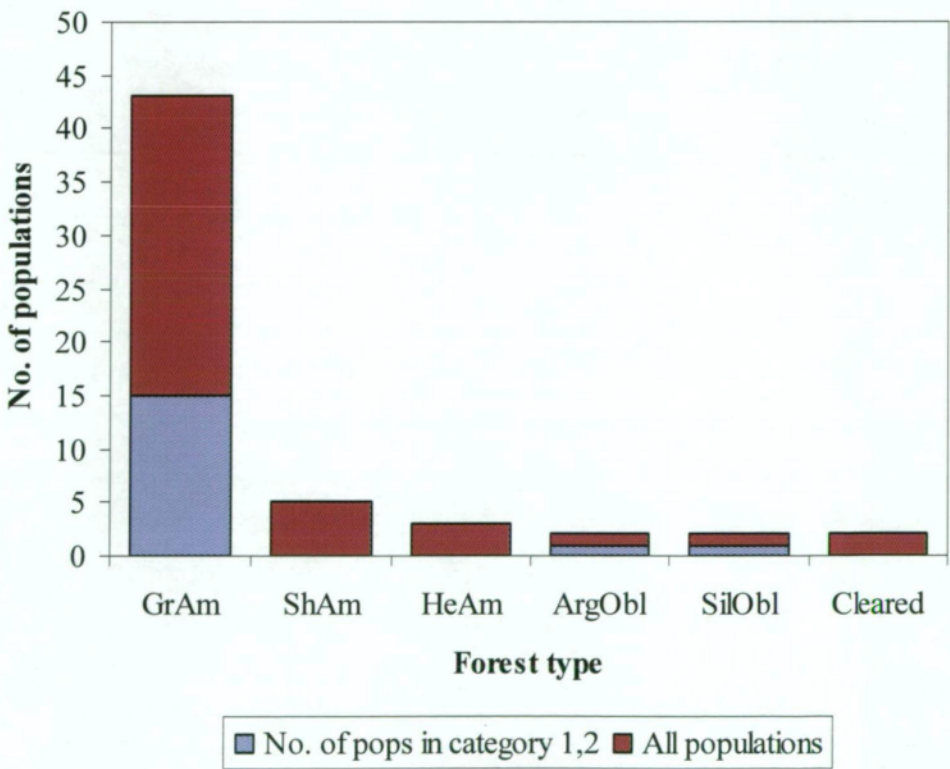
Location	1:25,000 Map	GR	Source	Yr last seen	Reliability	Search time (hr)	Comment
Mathinna	Mathinna	Near town	1	1961	1	3	searched near town
Mathinna E.	Dublin Twn	853039	3	?	2	2	marginal habitat
Windemere	Lilydale	029303	2,4	1996	1	2	
Avoca Road	Hanleth	487707	2,4	1990's?	1	1	grass taken over
Deddington Rd	Evandale	315902	4,3	1990's?	1	1	grass taken over
Isis Valley sth	Ellinthorp	222480	3	?	2	1	paddocks
Perth sth	Longford	166958	2	1984	1	2	thick grass
Perth west	Longford	122984	2	1990's?	1	2	thick grass present
West Frankford	Harford	695328	5	?	1?	1	marginal habitat
Franklin Riv.1	Harford	665315	2	1995	1?	1	heavy bracken
Franklin Riv.2	Harford	675325	3	1995	1?	1	marginal habitat
Tom Gibson	Cleveland	240770	5	1999	1	2	may be present
Macquarie Rd	Delmont	115719	2	1984?	1	2	marginal habitat
Birralee north	Exeter	850210	2,3	1980's?	1	1	heavy bracken/shrubs
Rowella 1	Bell Bay	929414	5.	1985	1	0	cleared
Rowella 2	Bell Bay	915405	5.	1975	1	0	cleared
Poatina	Poatina	995724	2	1984	1	0	pasture
Blackwood Ck	Poatina	937772	2	1984	1	2	Very grassy
Lefroy sth	Weymouth	056520	2	1995	1	1	
Beaconsfield	Beaconsfield	863389	5	1983	1	0.5	dense shrubs/weeds

Forty-nine specimens of *Brunonia australis*, from separate locations, were lodged with the Tasmanian Herbarium.



2.3.1.2 Forest Communities

*Brunonia* was most commonly found in grassy *E. amygdalina* forest (Duncan and Brown 1985) (Fig. 2.3). This forest type is incorporated into the broader ‘Inland *Eucalyptus amygdalina*’ forest type defined in the Tasmanian Regional Forest Agreement (Tasmanian Government 1996a). Several populations occur in shrubby and heathy *E. amygdalina* and *E. obliqua* forests but few of these are large healthy populations. Occasionally both grassy and shrubby *E. amygdalina* types occurred across a single population, or between isolated patches of a population, but the dominant type was recorded. One plant was recorded beneath *Allocasuarina* forest in Launceston’s Gorge Reserve but the majority of the population observed was beneath grassy *E. amygdalina* at the nearby Cambridge Street park.

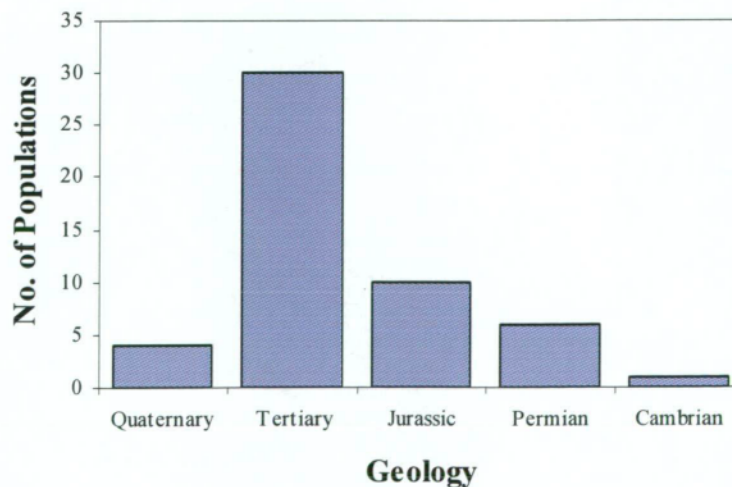


**Figure 2.3:** Forest type summary of the 58 known populations of *Brunonia australis* in Tasmania in 2001 by condition. (GrAM – Grassy *E. amygdalina*; ShAm – Shrubby *E. amygdalina*; HeAm – Heathy *E. amygdalina*; ArgiObl – Argillaceous *E. obliqua* forest; SilObl – Siliceous *E. obliqua* forest) (Status category 1, 2 populations- healthy and moderately healthy, all others struggling or threatened).

The densest populations of *Brunonia* are all in relatively open habitats but it can persist, even for years, in areas that are partially shaded by heavy bracken or shrubs. Preferred habitat is often dominated by native grasses and other herbs and forbs typical of grassy *E. amygdalina* forests of the Northern Midlands. Infrequently, a healthy population may be associated with an understorey containing sparse, low shrubs and heath species (e.g. Lefroy). Populations in heathy vegetation on sands around Beaconsfield, Exeter and the West Frankford (Franklin Rivulet) are generally small and struggling due to the dense competing understorey. Only four populations were identified beneath *Eucalyptus obliqua* dominated forest (Lefroy, Henry Somerset, Quamby Brook and Moriarty). Of these only the Lefroy population with a more open understorey and overstorey, had large numbers of individuals. Many of the understorey shrubs frequent in the *E. obliqua* forests were not common in the typical inland *E. amygdalina* sites and included *Pultenaea juniperina*, *Pultenaea gunnii*, *Lomatia tinctoria*, and *Acacia myrtifolia*. The TWINSpan analysis of populations provides further details of *Brunonia*'s occurrence in various forest communities (see 2.3.2.1 below).

#### 2.3.1.3 Geology and Soils

Peacock and Smith-White (1977) describe the likely association of *Brunonia* with Tertiary and Quaternary environments. Figure 2.4 shows the importance of Tertiary substrates for *Brunonia* in Tasmania.



**Figure 2.4:** Associated geological period for 51 populations of *Brunonia australis* in Tasmania.

Several populations were found on dolerite including two in the Ecclestone Road area, Brushy Rivulet, Danbury (near Legana), two at Bridgenorth, Trevallyn Conservation Area, and several small Launceston Parks in the Prospect area. Most were small except for the Ecclestone Road population but it is difficult to ascertain whether this is due to past management histories or factors associated with geology.

Various populations were located on Permian sediments such as mudstones and siltstones. The southernmost population was on mudstone but others included the Blackwood Creek and Railton areas. Various other geologies were also recorded including Ordovician quartzite, Phyllite and several alluviums and sands.

By far, most populations were found on sandy (and gravelly) loams and loams as classified by Northcote (1984) (Fig. 2.5). Several populations were on sands (e.g. Lefroy, Carr Villa). The species is not often found on clays and is recorded mostly from sandy soils on the mainland (Carolin 1992). Only 4 small populations were on clayey soils including 3 on clay loams and 1 on light clay. This may explain the lack of records in the extensive areas of dry *E. amygdalina* forest on dolerite such as north east of Launceston. It is unclear whether soil properties or dense vegetation associated with clay soils or other factors restricts *Brunonia* on these sites.

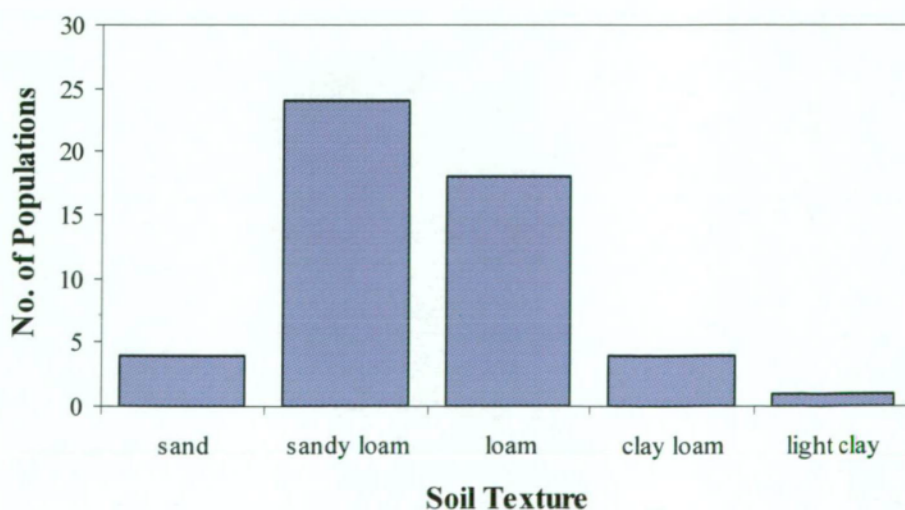


Figure 2.5: Soil texture of 51 populations of *Brunonia australis* in Tasmania.



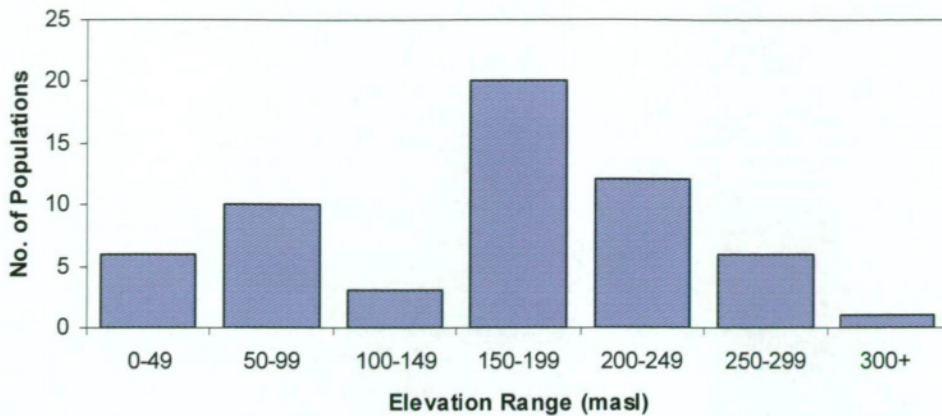
Table 2.5 summarizes soil chemical properties for the 51 populations sampled. No clear relationships could be found between any soil property and the success of *Brunonia* at a site. Healthy populations existed over the recorded range of nutrient levels, pH and electrical conductivity. Most populations are found on soils considered to have low-moderate nitrogen levels, moderate carbon and moderate total phosphorus levels (Grant *et al.* 1995). Three of the 4 populations with a *Eucalyptus obliqua* overstorey had very low levels of total N and total P (Lefroy, Moriarty, Henry Somerset) and this may restrict the density of competing understorey shrubs in these forests. Most populations would be considered low in available phosphorus and having a low electrical conductivity (EC) (Laffan *pers. comm.*). Soils were slightly acidic and within the normal range for Tasmanian soils (Grant *et al.* 1995).

**Table 2.5:** Summary of soil chemical properties for 51 *Brunonia* populations in Tasmania.

	Available P (mg/kg)	Total P (ppm)	EC (dS/m)	C (%)	N (%)	pH
Mean	3.87	130	0.040	2.9	0.165	5.50
Stdev	1.59	50	0.011	1.1	0.066	0.30
Range	1.27 - 8.58	50 - 270	0.020 - 0.072	1.0 - 5.0	0.037 - 0.343	4.66 - 6.18

#### 2.3.1.4 Environmental Conditions

Altitude range is 9 – 350 m a.s.l. although only the southernmost population is over 280 m on a small northeast facing hillside (Fig. 2.6). The lowest populations are adjacent to the Tamar River and Franklin Rivulet. Corrick and Fuhrer (2000) and Carolin (1992) infer that the species occurs in the snowfields region in Victoria and Foreman and Walsh (1993) list it as present beneath *E. pauciflora* woodland on the higher peaks around Mt Macedon (1013 m) and Mt Cole, Victoria. Several herbarium records for *Brunonia* are recorded in the Victorian snowfields region (e.g. near Corryong), but few altitudes are recorded, with the highest given, 500 m. The species therefore does not appear to be limited by cold conditions and in Tasmania it is more likely to be geological or vegetation factors that restrict its altitude range.



**Figure 2.6:** Elevation range of 58 Tasmanian *Brunonia* populations.

The mean annual rainfall range for populations in Tasmania is from about 600 mm in the Midlands areas to a maximum of about 1000 mm recorded for Blackwood Creek, close to the Western Tiers. Carolin (1992) reports the species as occurring in high rainfall areas in the mountains of the southeast mainland and the numerous records across the dry Australian interior indicate that it tolerates very dry conditions. Water-logging was observed to be detrimental in potted plants and the fact that sandy or gravelly soils are preferred, suggests that it cannot persist in areas of poor drainage.

#### 2.3.1.5 Landform

Virtually all populations occurred on slopes less than 15 deg. and more than 90% occurred on slopes less than 10 deg. All aspects were encountered, but generally sunny positions were more likely to contain *Brunonia*. The southernmost population was clearly confined to the northern face of a hillside.

### 2.3.2 Modeling of potential habitat

#### 2.3.2.1 TWINSpan analysis

The TWINSpan analysis table of flora species associated with *Brunonia* is included as appendix 1A. Three distinct '*Brunonia* communities' were recognized (Table 2.6):

1. Moist Inland *Eucalyptus amygdalina* sites

2. Dry Inland *E. amygdalina* sites
3. Heathy *E. obliqua* and coastal *E. amygdalina* sites

The first division was based principally on moisture and presence of species associated with disturbance, (Table 2.6). Group 1 consisted almost entirely of higher fertility, open, grassy Inland *E. amygdalina* forest types with fewer shrub and heath species and more native and weed species associated with disturbance, including: *Dichondra repens*, *Acaena novae-zelandiae*, *Acaena echinata*, *Centuarium erythraea*, *Schoenus apogan*, *Senecio* spp., *Galium* sp., *Plantago* spp., *Trifolium* spp., *Acetosella vulgaris*, *Rubus fruticosus*, *Linum marginale*, *Ulex europaeus*. Plants in group 2 included shrub, heath and higher strata species: *Allocasuarina littoralis*, *Pultenaea juniperina*, *Pultenaea gunnii*, *Leptomeria drupacea* and *Davesia latifolia*, and species from drier sites, including: *Platylobium obtusangulum* (Curtis 1993a), *Acacia genistifolia* (Curtis 1993a), *Acacia myrtifolia* (Curtis 1993a), *Kennedia prostrata* (Curtis 1993a), *Lomatia tinctoria* (Curtis 1993b), *Allocasuarina littoralis* (Curtis 1993b), *Opercularia varia* (Curtis 1967). The second division of group 2 is the only other division of significance, where dry Inland *E. amygdalina* sites were separated from heathy *E. obliqua* and coastal *E. amygdalina* sites (Table 2.6). Healthy *Brunonia australis* populations were found in both moist and dry Inland *E. amygdalina* sites but *E. obliqua* and coastal *E. amygdalina* sites are normally marginal habitats, with few populations in good condition.

**Table 2.6:** Summary of TWINSPAN divisions of Tasmanian *Brunonia australis* populations based on 168 recorded species at 74 sites.

<b>DIVISION 1 into 2 groups</b>							
<b>Group 1      <i>BRUNONIA</i> COMMUNITY 1</b> More fertile and / or higher rainfall sites Inland <i>Eucalyptus amygdalina</i> sites – higher fertility  Distinct group of disturbance lovers including preferential species: <i>Senecio spp.</i> , <i>Dichondra repens</i> , <i>Schoenus apogan</i> , <i>Geranium spp.</i> , <i>Plantago spp.</i> , <i>Acaena spp.</i> , <i>Galium spp.</i> , <i>Centaurium erythraea</i>				<b>Group 2</b> Lower fertility and / or lower rainfall sites Inland <i>Eucalyptus amygdalina</i> sites –lower fertility, Coastal <i>E. amygdalina</i> sites, <i>E. obliqua</i> sites  Includes more heath species, low fertility associated species including indicator species <i>Allocasuarina littoralis</i>			
<b>DIVISION 2 into 4 groups</b> (not a useful additional division for group 1)				<b><i>BRUNONIA</i> COMMUNITY 2</b>		<b><i>BRUNONIA</i> COMMUNITY 3</b>	
Group 1.1		Group 1.2		2.1		2.2	
5 heavily disturbed sites with few higher strata species (shrubs and taller heaths)		Bulk of group with more higher strata species		Typical low fertility inland <i>E. amygdalina</i> sites e.g Powranna, Deddington and some in the Launceston area (Punchbowl, Kate Reed, Carr Villa, Relbia)		All <i>E. obliqua</i> (non- <i>E. amy</i> ) sites and coastal heathy <i>E. amygdalina</i> sites.	
<b>DIVISION 3 into 8 groups</b>							
1.1.1	1.1.2	1.2.1	1.2.2	2.1.1	2.1.2	2.2.1	2.2.2
not a useful further division		not a useful further division		not a useful further division		not a useful further division	
2 very heavily disturbed sites (gravel quarry Powranna & roadside edge Devon Hills)	Includes 2 logged sites at Blackwood Creek	Generally small area populations	Variety of populations including large B.a. pops in the Bracknell, Carrick to Westwood districts	Low fertility <i>Inland E. amygdalina</i> sites (mainly on tertiary alluvials)	A single small pop. at the Gorge - Launceston	As above except for 2 heathy sites.	2 heathy sites on West Tamar with very poor <i>Brunonia</i> numbers (Cronin's at Exeter and Beaconsfield pop's.)

#### 2.3.2.2 Model

Model 3 (Fig. 2.7) included most of the recorded *Brunonia* populations and was considered more reliable than models 2 and 3 (appendix 1C) because it discounted the southeastern areas near the Freycinet Peninsula, where there are no reliable records. Interestingly, despite excluding *E. obliqua* sites from the model, the TASVEG vegetation layer had included some of them as *E. amygdalina* forests, (e.g. Lefroy in the north), and they remained in the modeled area.

The model shows the scarcity of potential sites in the core known habitat area between Launceston and Epping Forest / Conara. It also reflects the low probability of sites being relocated in the Mathinna area or Fingal Valley, which is likely to be a consequence of vegetation clearance of preferred habitats in these areas.

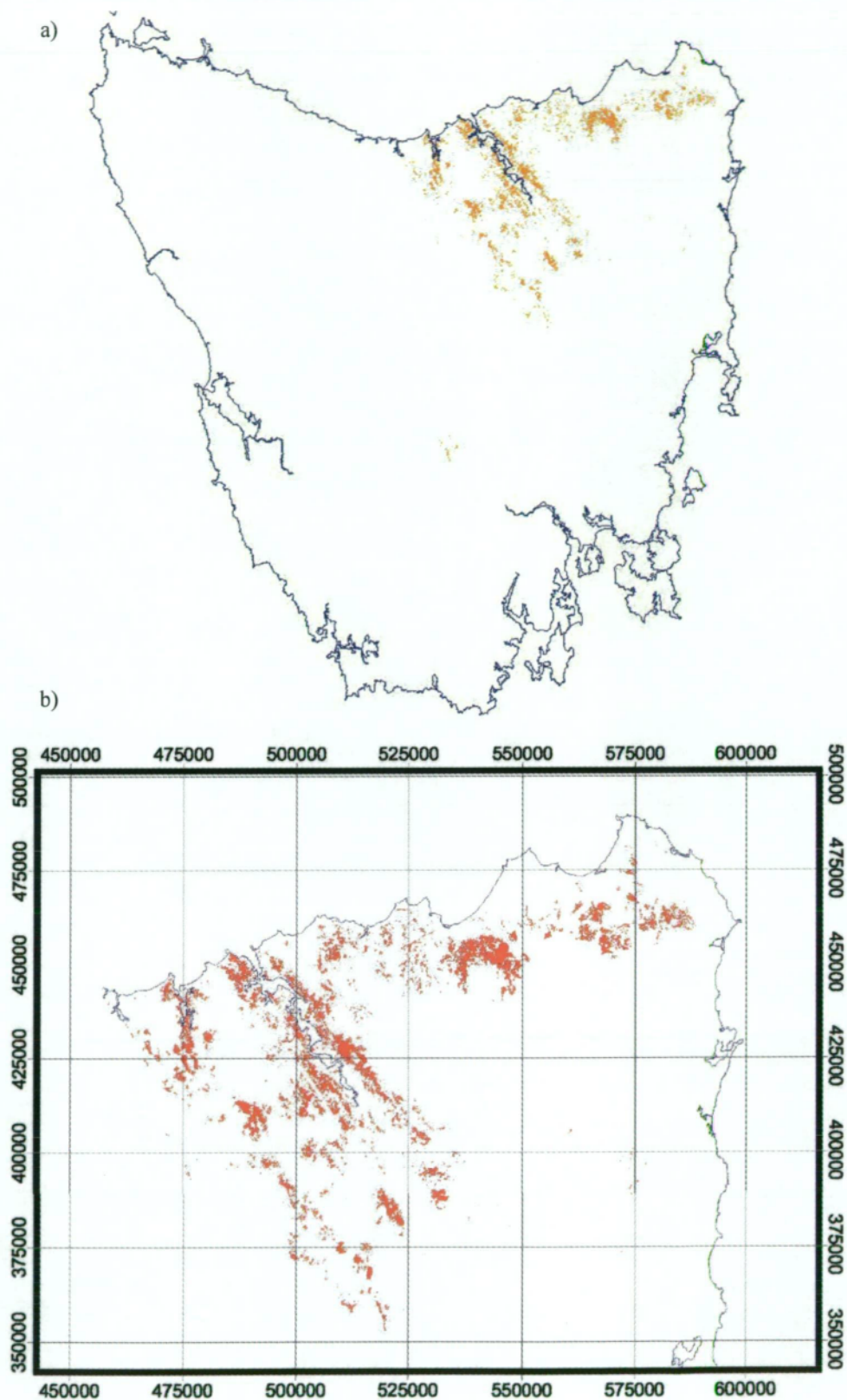
The model predicts several areas where *Brunonia* is not known or only known in isolated patches.

They may be summarized as:

- **Northwest** – (Port Sorell to Franklin Rivulet area). Possible sites present particularly in dry open forests in the Port Sorell area. Large areas in the Franklin Rivulet area contain poor habitat with dense heathy and shrubby understorey.
- **Brushy Rivulet** (north of Westbury). Areas west of the Brushy Rivulet and Selbourne populations. Possible habitat for *Brunonia* in this area.
- **Northwest Tamar**. Some recent populations have been identified in this region near Beauty Point and there are reports of a population at Yorktown historic site. Much of this area is coastal *E. amygdalina* forest and would be marginal habitat but some populations may be present.
- **East Tamar**. Previously reported populations at Windemere and Mt Direction support the possibility of more populations in the East Tamar region. However, based on field investigations in this area, some of the modeled area includes *E. amygdalina* forest on dolerite where soils have higher clay content than other areas typical of *Brunonia*. Nevertheless, this region also includes areas of sandy soils where some populations may be located.

- **Bridport.** A large area has been identified as potential habitat between Bridport and Scottsdale. Open dry forests in this area appear capable of supporting *Brunonia* populations. No populations have been previously (reliably) recorded there.
- **Far northeast.** Coastal *E. amygdalina* forest would be the main forest community in this region and, therefore, while potential populations may occur, the area is likely to be of marginal suitability due to denser heathy or shrubby understoreys.

The use of only vegetation and geology layers provided a reasonable model of potential distribution (model 1, appendix 1C). It included areas in the southern midlands and east coast that were omitted in the second model which applied temperature, elevation, rainfall and slope parameters. The omission of most of the east coast in the final model was mainly due to the inclusion of the 'range from the wettest to driest month' parameter. This implies that Tasmanian *Brunonia* populations may be sensitive to extremes in monthly rainfall supply but it is uncertain what mechanisms drive this response. On the mainland *Brunonia* occurs in regions subject to wet and dry seasons so it is unlikely to be directly affected by monthly rainfall extremes. It may be a secondary response to other vegetation or soil factors related to this weather pattern and which are unique to Tasmania.



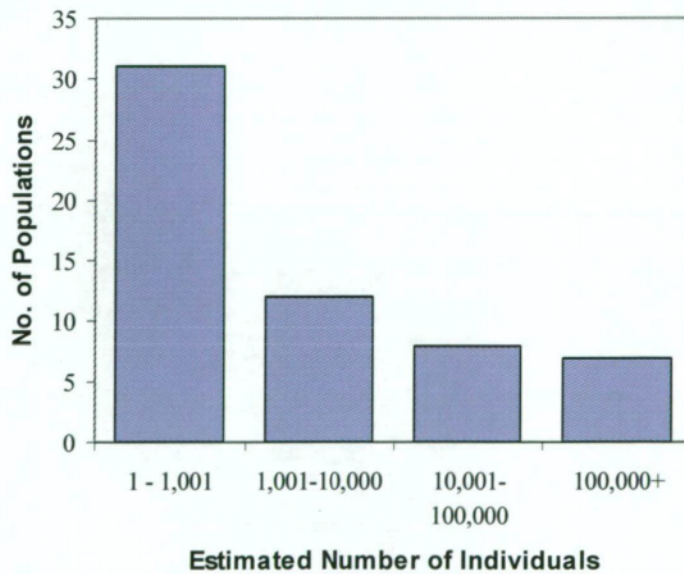
**Figure 2.7:** Modeled potential *Brunonia australis* habitat in Tasmania (model 3) depicting a) Tasmania; b) northeast region.



### 2.3.3 Conservation status of Tasmanian *Brunonia* populations

#### 2.3.3.1 Population size

The data suggest that many populations of *Brunonia* are under threat and that the species continues to face further decline. The breakdown of the 58 populations by estimated number of individuals is depicted in figure 2.8. Over 50% of populations had less than 1000 mature individuals. Numbers of individuals were hard to determine even in small populations due to the plants' multiple rosettes but the estimates indicate the relative abundance of the species across its distribution. Populations with less than 10,000 individuals should be considered small for *Brunonia* because many populations in this size range were fragmented sub-populations or covered only small areas. Nearly 75% of populations contain less than 10,000 plants. *Brunonia* sometimes forms very dense clusters and a population of up to 10,000 plants may cover, in clumps, a relatively small area of several hectares. Counts by the author have indicated densities of up to 50 rosettes/ m<sup>2</sup>. Assuming an average of two rosettes per plant it is conservatively estimated that densities of 5000 plants/ha (1 plant per 2m<sup>2</sup>) are possible.

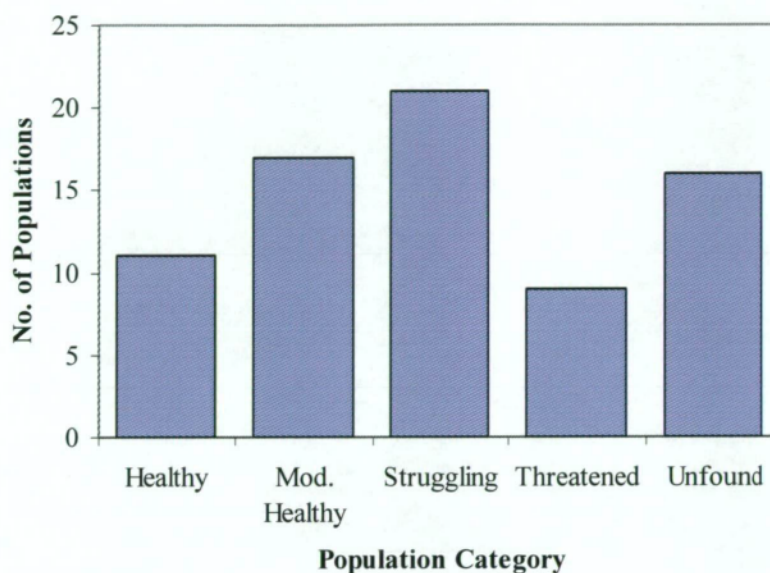


**Figure 2.8:** Population size distribution for the 58 known populations of *Brunonia australis* in Tasmania in 2001.



### 2.3.3.2 Conservation classification

After taking into account population size and factors causing decline, the species is facing further significant decline in Tasmania (Fig. 2.9). Over 15% of existing populations are facing extinction during the next decade under current management and more than a third are considered to be struggling. As expected, the majority of these are small populations.



**Figure 2.9:** Assessment of the status of *Brunonia* populations in Tasmania based on field visits to 74 known sites and sites with reliable historical records.

Of the larger populations over 100,000 individuals, 3 have some form of formal reservation and several other smaller populations are contained in either formal or informal reserves (Table 2.7). In addition, various Launceston suburban parks contain the species. Most populations remain in private ownership (65%), with the remainder occurring on council managed land and under various Government tenures (Fig. 2.10).

Under Tasmanian guidelines, *Brunonia* could be downgraded from vulnerable to rare as a result of the large number of populations and individuals (Threatened Species Unit 2004). The species

qualifies as rare under Rule A – at risk of increasing threat status due to ongoing declines and Rule A1 – extends over an area of less than 100x100km.

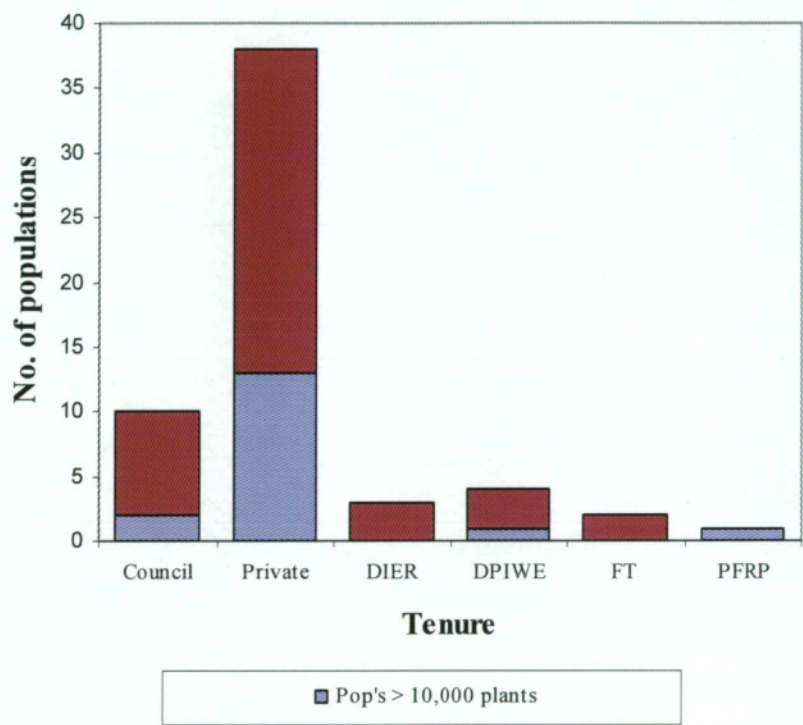
**Table 2.7:** Populations of *Brunonia australis* that have some form of reserve management in place as at Jan. 2002.

Population name	Reserve name	Whole/part of population	Lowest no. of plants estimated	Area occupied (ha)
Powranna	Powranna Nature Reserve	part	700,000	125
Lefroy	Lefroy Forest Reserve	whole	200,000	8
Carrick West	Private management agreement (1 landowner)	part	200,000	28
Norwood	Punchbowl Conservation Area Carr Villa Conservation Area	part	70,000	11
Brushy Rivulet	Brushy Rivulet Nature Reserve	whole	3,000	4
Prospect	Kate Reed State Reserve	part	2200	2
Henry Somerset	Henry Somerset Orchid Reserve (private reserve Gunns Ltd)	whole	2000	10
Moriarty	Private management agreement	whole	600	4
Franklin Rivulet	Franklin Rivulet Forest Reserve	whole	300	0.25
Trevallyn	Trevallyn State Reserve	whole	200 +	1
Tom Gibson	Tom Gibson Nature Reserve northern addition	whole	6 (0 in 2000)?	0.01?
Gorge	Launceston Gorge Reserve	part	1+	0.01
<b>Total</b>		<b>12 part or whole populations</b>	<b>1,178,307</b>	<b>193.27</b>
<b>% of all populations</b>		<b>21%</b>	<b>44%</b>	<b>24%</b>

The large number of small and at risk populations (approximately half) and the nature of the reserves is important. Powranna is by far the largest population both in area (125ha) and number of individuals (700,000), and gives a biased picture of the overall reservation status of the species.

Lefroy is an isolated population with a high density of individuals but is a small (8ha) and potentially vulnerable area. The Norwood population has a small and disjunct distribution. At present the bulk of the Carr Villa patch, outside the 6ha reserve, is destined for cemetery expansion. Additionally, the effects of changes in management approach on recent reserve additions and agreements, particularly in relation to grazing regimes, is yet to be shown. The grassy *E. amygdalina* forests and woodlands,

where *Brunonia* is predominantly found (Fig. 2.3), are amongst the most depleted forest types in Tasmania (Kirkpatrick and Gilfedder 2000). While some of these forests have been protected since the commencement of this study a large proportion still remain unprotected and in private ownership. Therefore it is appropriate that *Brunonia* remain on the threatened species list, perhaps as rare (schedule 5 of the TSPA 1995), rather than vulnerable (schedule 4).



**Figure 2.10:** Tenure (management) summary of the 58 known populations of *Brunonia* in Tasmania in 2001 by population size greater or less than 10,000 plants. (DIER: Dept. of Infrastructure, Energy and Resources (road reserves); DPIWE: Dept. of Primary Industry, Water and Environment; FT: Forestry Tasmania; PFRP: Private Forest Reserve Program).

2.3.4 Threatening Processes in Tasmanian *Brunonia* populations

2.3.4.1 Historic influences on *Brunonia* populations

Various reasons contributed to the decline of *Brunonia* areas where it was previously recorded but could not be found in 2000 (Table 2.4), including: clearing (Avoca Rd, Deddington Rd), naturally small population (Birallee, Frankford, Tom Gibson), grazing pressure (Perth area), and logging or clearing (Macquarie Rd, Mathinna, Windemere). Despite the assertions of the Regional Forest



Agreement Report (Tasmanian Government 1996b) there was no evidence observed or found in the literature that could attribute *Phytophthora* infection or fertilizer addition as threats to *Brunonia*. The sources of this report are not known. Figure 2.12 summarises historic factors that were determined to have had a negative impact on current populations. Grazing and clearing history combined have had the major impact in the past, negatively affecting more than half of the current populations.

#### 2.3.4.2 Current Threatening Processes

The small and fragmented condition of many populations is the factor currently most threatening the range of the species in Tasmania (Fig. 2.13). Even some of the larger populations, in terms of numbers of individuals, are spatially fragmented and are at risk of further decline as the smaller component sub-populations face various threatening processes. The Norwood population in Launceston is a good example where an overall large number of individuals are fragmented between Carr Villa, which faces potential cemetery expansion, small patches at Hawthorne St Park, Launceston Golf Course, Punchbowl Road and the Punchbowl Reserve population, which needs long term active management to limit the development of a thick shrubby understorey (Fig. 2.11).



**Figure 2.11:** *Brunonia* (indicated by arrows) is restricted to the edge of walking tracks and clearings in many Launceston parks and reserves due to significant thickening of understorey vegetation.

Small population size is more accurately defined as a condition, but was included as a threatening process (Figs. 2.12 and 2.13) as a predictor of the potential demise of some populations. The small size of a population means that it is more at risk of extinction from a wide range of events, including: increased competition from other plants, clearing and other significant disturbances, changes in grazing regime, or disease.

In some cases, grazing was not considered a current threatening process when the grazing regime employed had not seriously impacted the population (e.g. Glen Stuart, Deddington, Carrick).

Logging was considered a threatening process where it occurred, but the actual impact may vary greatly between logging intensities and subsequent influences such as grazing or weed invasion.

Timber plantations had been established over two populations in the Blackwood Creek area, seriously impacting one entire population and part of the other. *Brunonia* was observed, over a 3 year period, to recover poorly following plantation establishment. There was limited recovery in the first year between mounds where herbicide application was patchy, but disappeared in the following years as canopy cover increased and weed species such as *Holcus lanatus* (fog grass) proliferated. Generally, any process requiring clearing, such as timber plantation establishment, gravel extraction or agriculture is now restricted by a moratorium on clearing forest types typically containing *Brunonia* (Forest Practices Board 2003). Some small scale clearing is still possible and clearing for the Carr Villa cemetery may substantially affect that part of the Norwood population.

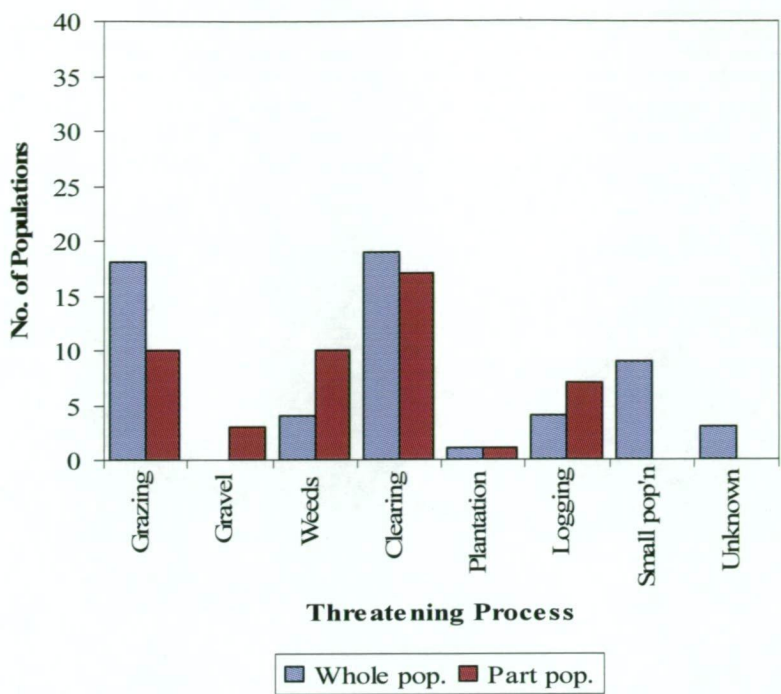
Most reserve areas were assigned the “lack of disturbance regime” as a threatening process in figure 2.13. This may not occur if there is targeted management for understorey diversity in these areas. Some of the recent reserves in the Private Forest Reserve Program may allow grazing at certain times of the year, which could enhance the *Brunonia* population. Other reserved populations on poorer substrates, such as Lefroy, may not be at risk of a thickening understorey.

Periodic disturbance may be important for the persistence or expansion of *Brunonia* at a site.

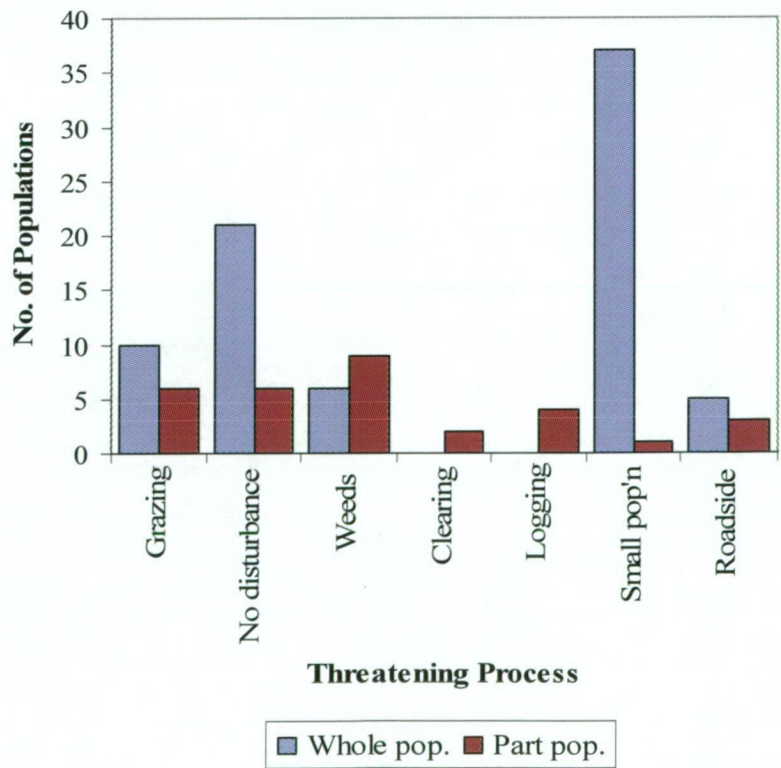
Kirkpatrick and Gilfedder (1999) suggest disturbance is important for recruitment. Some herbarium entries record *Brunonia* in disturbed habitats such as roadsides or burnt spinifex areas. The

Tasmanian Regional Forest Agreement (Tasmanian Government 1996b) reports roading, mining and quarrying and general disturbance as beneficial to the species. While it is often seen in disturbed habitats, it is unlikely that roading and quarrying are actually beneficial to the species. Observations on populations in Tasmania suggest that individuals found on road cut batters are mainly survivors or occasionally germinants from nearby individuals that existed prior to the disturbance. The road or quarry itself impacts heavily on the species as can be seen at the Deddington and Powranna populations where, despite many years of recovery time, quarrying for ironstone gravels has left only a few survivors on the edges of severely disturbed sections. The small Beaconsfield population on Bowens Jetty road is apparently now extinct (2004) due to continued grading of the roadside batter. Occasional light mechanical soil disturbance may be beneficial by opening up the understorey and providing germination opportunities but the species does not appear to recolonize expansive, heavily disturbed areas in large numbers through germination of soil stored or introduced seed.

Fire may be beneficial, at least in the short term, but several populations were observed where thick bracken and wattle were restricting the success of *Brunonia*. Inappropriate fire regimes may increase the cover of bracken and wattle. Tolhurst (1996) proposed that, in Victoria, disturbance in spring is more likely to encourage bracken growth than disturbance in late summer and autumn. Thick bracken cover was noted in some populations in the more fertile, higher rainfall areas of *Brunonia*'s distribution, including the Carrick and Bracknell districts on Tertiary alluvial soils.



**Figure 2.12:** Factors historically negatively affecting *Brunonia* populations in Tasmania.



**Figure 2.13:** Factors currently threatening *Brunonia* populations in Tasmania.

## 2.4 Conclusion

The data suggest that due to a high number of small, fragmented populations, *Brunonia australis* faces further significant decline in Tasmania. It tolerates a range of environmental conditions in the lowland dry forests in the north of the State but inappropriate management regimes in these areas will see the continuing retraction of populations. Periodic disturbances that maintain a relatively open understorey and reduce competition appear to favour the species particularly in areas of higher fertility. Some grazing or slashing in reserved areas may be required. On the other hand, heavy disturbances such as clearing or inappropriate disturbance regimes such as constant sheep grazing may eventually eliminate the species from a site. It is recommended that *Brunonia* remain listed on the *Threatened Species Protection Act (1995)*. While the species may technically be downgraded to 'rare' (Schedule 5) under Tasmanian guidelines, the large number of populations at risk of continuing decline suggests that *Brunonia* should be retained on Schedule 4 of the *Threatened Species Protection Act (1995)* as 'vulnerable'. Important populations should be monitored approximately every 5 years, or more regularly if there have been changes in management regime.

## 2.5 Acknowledgements

Gaining information covering a wide number of locations and factors involved the help of many people. Wendy Potts, Naomi Lawrence and Eve Lazarus from the Threatened Species Unit, Dept. of Primary Industries, Water and Environment provided valuable data and help with conservation classification. Phillip Pennington and staff from the Cooperative Research Centre for Sustainable Production Forestry and Mike Laffan (Forestry Tasmania) provided technical analysis and advice on soils. Many people gave advice on population locations including Steve Casey, Richard Barnes (Private Forests Reserve Program), Chris Moore (Launceston City Council), and Fred Duncan and Mark Wapstra (Forest Practices Board) who also provided assistance with plant identifications. Mark McRostie and Melanie Dare of Gunns Ltd assisted with production of distribution maps. Many private landowners, too numerous to mention, gave up valuable time to assist with location of populations on their properties.



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### 3. Reproductive ecology of the threatened herb *Brunonia australis* (Brunoniaceae) in Tasmania

Craig Hawkins and Dr Robert Wiltshire

**Abstract.** *Brunonia australis* Sm. ex R. Br. is an attractive herb, widely distributed on mainland Australia, but a threatened species in the central north of Tasmania due to a restricted distribution and threatening processes such as livestock grazing. Despite the potential as an ornamental, little of the reproductive characteristics of the species has been reported in the literature. This study examined flowering phenology and fecundity, pollination, seed dispersal, germination and potential for retention in a soil seed bank in *Brunonia australis*. Results indicated that *Brunonia* prefers open habitats where it flowers readily in summer with a peak flowering time in December. Pollination occurs through a variety of common insect vectors and a relatively high fertilization rate of 59% was observed for one population. Seed dispersal by wind and animal vectors was found to be limited. Germination in the laboratory occurred readily without any apparent dormancy mechanisms. 98% of seed buried in the soil either germinated (81%) or were rendered unviable, mainly by soil microorganisms within 2 months. If an open understorey is maintained and disturbance minimized during flowering and seed set, *Brunonia* populations should persist or increase at a site by sexual reproduction. However, if isolated populations are destroyed, the poor seed dispersal of the species will limit its ability to recolonize. Further research should investigate the minimum viable population size, self-incompatibility and the implications for seed viability across populations.

#### 3.1 Introduction

*Brunonia australis* Sm. ex R. Br. (blue pincushion) is an attractive Australian herb with potential for horticultural development (e.g. Hamilton 1913, Carolin 1992a, Fuss and Evans 1995). Fuss *et al.* (1996) ranked the species as having the greatest potential for use as a bedding plant, from a range of Western Australian wildflowers, following an industry survey and germination trial.

The species is widespread in all mainland Australian states and territories but has a limited distribution in the north of Tasmania where it is considered a threatened species. The reproductive ecology of *Brunonia australis* has received little focussed attention in the literature. The interesting flower morphology of the species has been discussed (e.g. Carolin 1959, 1960, 1966; Leins and Erbar 1989; Howell *et al.* 1993), germination characteristics (Hitchmough *et al.* 1989; Fuss *et al.* 1996; Delpratt 1996; Morgan 1998), cytology (Peacock and Smith-White 1977) and systematic relationships (Carolin 1977), however, collation of information on the species is limited to brief accounts in various floras (e.g. Curtis 1963; Stanley and Ross 1986; Carolin 1992a).

An understanding of the life cycle of *Brunonia* is critical for determining the management of remnant populations in Tasmania (Clarke 2000). While much information abounds on the seed dispersal of trees and commercially important plants, relatively little is understood about the dispersal of herbaceous species (Cain *et al.* 1998). Some knowledge of flowering, seed production potential and dispersal, seed banks and germination requirements will aid knowledge of the species ability to persist in an area or recover from disturbances. Determining the degree of specialization in pollination systems will also, in part, help determine sensitivity to environmental change (Johnson and Steiner 2000). Given the fragmentation and disturbance of much of the potential habitat of *Brunonia* in Tasmania, an appreciation of its mode of dispersal will aid understanding of its ability to recover from disturbances and increase its range.

Germination requirements of herbaceous plants vary enormously between species (e.g. Grime *et al.* 1981; Baskin and Baskin 1988; Bell *et al.* 1993). Some of the major factors tested in this study were: temperature including diurnally fluctuating temperatures (e.g. Mott 1972; Toole 1973; Thompson and Grime 1983; Willis and Groves 1991), stratification (Baskin and Baskin 1988; Willis and Groves 1991), darkness (McIntyre 1990; Morgan and Lunt 1994), and scarification of the seed coat (Ballard 1973). In recent years several authors have also shown the importance of smoke in germination (Dixon *et al.* 1995), heat shock, through the action of fires (Mott and Groves 1981; Bell *et al.* 1993 provide summaries) and the interaction of both heat shock and smoke (Keith 1997). Although the mechanisms are not fully understood, germination of many species is also stimulated

by nitrate (Hendriks and Taylorson 1974; Karssen and Hilhorst 1992). The indehiscent fruit is the main dispersal unit of *Brunonia* and much time is required to 'clean' the seed from this body. A replicate was added in this study to determine the readiness of germination from within the fruiting body.

Persistence of seed in soil is important in the recovery and composition of plant communities following disturbance (Carroll and Ashton 1965; Thompson and Grime 1979; Warr *et al.* 1993). Species not apparent in a community may regenerate following disturbance through the presence of stored seed in soil (Howard and Ashton 1967; Thompson and Grime 1979) but the capacity of *Brunonia* to do so is unknown.

A range of experiments and observations were made to determine some of the main elements of the reproductive requirements of *Brunonia* in Tasmania, a state in which the species has been neglected. Flowering attributes, pollination, seed dispersal and germination characteristics were investigated.

## 3.2 Methods

### 3.2.1 Study site

The main study site was a 15 hectare privately owned, 'inland *Eucalyptus amygdalina*' (black peppermint) forest on Tertiary alluvial soil (GR 932907 Cluan 1:25,000 mapsheet). The stand was dominated by mature and over-mature *E. amygdalina* with occasional *E. viminalis* (white gum). The site was selectively logged in 1998 and was previously subjected to light grazing by sheep and cattle. No fire was known to have occurred in the area for more than twenty years. The understorey was generally open and dominated by herbs and grasses with frequent, denser patches of *Pteridium esculentum* (bracken).

Elevation of the site is approximately 210m a.s.l., landform was uniformly flat and annual average rainfall is 820mm with a winter bias. Weather details were recorded at "Sand Park", Bracknell, 3km southeast of the study site.

### 3.2.2 Flowering phenology

#### 3.2.2.1 Population flowering period

The duration of flowering was monitored in summer 2000/2001 to determine the population flowering period of *Brunonia* in the Bracknell study site. Eighteen 1x1 metre plots were randomly located across the main study area in early September 2000 before the elongation of any flower stalks. The number of *Brunonia* rosettes in each plot were counted and the number of plants estimated. The number of flowers and the number of rosettes with flowers in each plot were counted approximately once a week until flowering ceased. The maximum number of flowers deriving from an individual rosette and the total number of rosettes bearing flowers were also recorded. Flowering of propagated plants and other populations was also observed over several seasons. The general flowering periods of *Brunonia* across Australia as recorded in the literature were also summarized.

#### 3.2.2.2 Individual flowering period

Individual inflorescences were monitored in summer 1999/2000 to determine the average flowering time of an inflorescence in the field. Before the onset of flowering, 21 plants with 57 developing flower heads were identified with steel pegs and flagging tape. Commencement of flowering was defined as one or more florets displaying their petals. Presence/absence of open florets on each flower head was recorded every 3-5 days (nine days between 5th-15th December and 11 days between 21 December and 2 January). Given the time lapse between observations, maximum flowering period was determined as the maximum possible period between commencement and cessation of flowering. Minimum flowering period was determined by assuming that flowering commenced the day before it was first observed to the day after it was last observed. Average duration of flowering is the average between the maximum and minimum periods. Maximum and minimum flowering period was only recorded for flower heads with a confidence of  $\pm 4$  days. Therefore, any flower heads commencing between 5 and 15 Dec, and/or finishing between 21 Dec and 2 Jan were excluded. Peak flowering period is defined as the observation day when most flower heads were known to be in flower.



### 3.2.2.3 Flowering and fruiting capacity

Two typical flower heads in apparent full flower were chosen from the main study area to determine the number of florets in an individual inflorescence. The number of fruits following anthesis was also measured.

Eighteen average sized fruiting heads were collected between 22 and 27 January 2000 before seeds were shed and placed into separate plastic bags. The numbers of both nonviable and potentially viable diaspores were counted. Potentially viable fruits were determined with a light squeeze between the fingers identifying the presence of a seed. The calyx was removed from questionable samples to determine the status of the seed. Experience from germination experiments, discussed below, showed this method to be a reliable indicator of seed viability.

### 3.2.3 Invertebrate Pollination

During the main flowering period, a daylight search for invertebrates visiting *Brunonia* flower heads was conducted at several populations on different days in two summers. Observed invertebrate visitors were caught with a 300mm butterfly net. Insects were pinned and identified at least to family level.

### 3.2.4 Seed Dispersal

#### 3.2.4.1 Seed dispersal – wind

A selection of 120 typical fruits containing viable seeds pooled from the main study area were dropped in groups of ten onto black plastic from a five metre height in an enclosed shaft. The time taken for the bulk of the fruits to hit the plastic was measured with a stopwatch. Due to the spread of fall and subsequent difficulty in accurately timing when the bulk of seeds hit the bottom, the experiment was then repeated to time the fastest fruit to hit the plastic (8 replicates) and the slowest (nine replicates).

Potential for wind dispersal was then calculated using the following formula (from Pasquill and Smith 1983):

$$x = Hu/F$$

where  $x$  - is the predicted horizontal distance in metres from the seed head to deposition site

$H$  - is the height of the seed head (assumed as 0.3m for *Brunonia* in this study)

$u$  - is the horizontal wind velocity in metres/second averaged between  $H$  and the ground.

$F$  - is the descent speed calculated in metres/second from the drop test described above.

The weight of 100 fruits was measured to gain an average weight of the *Brunonia* dispersal unit. The seed was then removed from each fruit and the weight retaken.

#### 3.2.4.2 Seed dispersal – vertebrate

Three simple tests were conducted to determine whether *Brunonia* fruits were likely to be dispersed by attachment to animal fur. The skin of a dead Bennett's Wallaby (*Macropus rufogriseus*) was dragged through 3-5 seeding heads of live *Brunonia* plants in the field. Any fruits caught in the fur were counted. The fur was then given a light shake and a second count made. Eight replications were made. The Bennett's Wallaby was chosen as a skin was readily available and it is a common native animal occurring across the range of *Brunonia*.

The second test involved brushing 'full' seed heads of *Brunonia* along the underbelly portion of the fur as it was held vertically by the tail over a black plastic sheet. Each head was run down the fur, two to three times, to simulate movement of the animal through a patch of seed heads. The number of fruits caught in the fur were counted. A light shake was given to the fur for approximately three seconds and then another count of fruits still in the fur recorded. Finally a more vigorous shake was applied and a final count made. Thirteen replications were conducted.

In order to apply a more repeatable experiment, a further test was made by placing the fur on a black plastic sheet on the floor and dropping 50 fruits from approximately 30cm. The skin was then

carefully turned over horizontally above a black plastic sheet and the number of fruits retained in the fur determined. The fur was then given a light shake and then a more vigorous shake while held horizontally and the number of fruits retained in the fur determined after each shake.

For comparison, the final experiment was repeated for ten fruiting heads of the well-known adhesive disperser *Acaena novae-zelandiae* (buzzy). Ten replications were conducted. Average percentage retention of fruits after each treatment (gravity, light shake and heavy shake) were compared using a two-tailed students t test ( $\alpha = 0.05$ ).

### 3.2.5 Germination

#### 3.2.5.1 Laboratory germination tests

##### *Test procedures*

Seeds were collected over an area of approximately 4-5 hectares from the Bracknell study site on two occasions in February 1999. Seed heads (inflorescences following anthesis) were picked if easily broken off the scape. Seed heads that did not readily break off were considered to potentially contain seed that was still developing. Fruits were stored in brown paper bags at ambient temperature. Removal of the seed from its fruit was undertaken by hand from April to July 1999 and stored in the same way as the fruits. Each seed was examined by dissecting microscope and malformed or damaged seed discarded. Seeds were thoroughly mixed, to randomize the possibility of individuals from the same inflorescence occurring in the same treatment.

Six replicates of 25 fruits/seeds were prepared for all treatments. Seeds and fruits were placed in petri dishes on 131 micron Advantec filter paper over an even bed of vermiculite. Approximately 18-20ml of boiled tap water, cooled to room temperature, was added prior to placement of seeds and fruits on all treatments except the hot water and smoked water treatments which were poured over the seeds. 20ml of 0.2% Potassium nitrate was added to that treatment rather than the normal water addition. All seeds and fruits were sprayed with 1g/l Benlate fungicide and petri dishes sealed with parafilm.

Germination trials were conducted in purpose built, water-heated, germination tanks, styled on Copenhagen Tanks, at the Department of Primary Industries, Water and Energy seed-testing laboratory, Prospect. Germination tanks were contained within a temperature controlled room (constant 20°C.  $\pm$ 2 °C) with ceiling lighting of 750 lux, 1200mm, Sylvania “Fluoro Gro-lux” fluorescent tubes with a photosynthesis promoting pink tinge.

A malfunction of the tanks precipitated the end of testing after day 74 of all treatments except the stratified seeds, which had been in the tanks for 29 days. In order to continue testing, the stratified seed treatments were transferred to a Labmaster incubator kept at a constant 20°C ( $\pm$ 1°C) for a further 21 days.

At the end of testing, the viability of ungerminated seeds was determined by squashing with tweezers.

The following treatments were applied:

i) Control:

Control conditions were 15°C/25 °C for a 15hr/9hr thermoperiod respectively and 13hr 20min/ 10hr 40min photoperiod respectively. Lights came on one hour prior to increasing temperature and went off 40 minutes after the temperature decline. Dishes were checked at 3-4 day intervals for the first 40 days and approximately weekly thereon and any germinants or losses due to fungal attack, counted and removed. All treatments were tested under these conditions unless otherwise stated.

ii) 30/20:

A second germination chamber was used at a 30 °C (light)/20 °C(dark) temperature fluctuation over the same thermoperiod and photoperiod as the controls.

iii) Dark:

Aluminium foil was wrapped around petri dishes and germination checked at three fortnightly intervals and approximately weekly thereafter. Seeds were exposed to approximately two minutes of light at each observation date.

iv) Smoked water at room temperature (SW cool):

Regen 2000<sup>TM</sup> SMOKEMASTER mixture was used in both smoked water treatments. As previous experiments had shown it encouraged fungal attack, the concentrate was boiled for approximately two minutes in an effort to sterilize it, and then diluted to 10%. The dilution was allowed to cool to room temperature and 18-20ml poured over the seeds.

v) Smoked water heated to 98 °C (SW heat):

The 10% dilution was re-boiled and poured over seeds at between 95-98 °C

vi-viii) Hot water treatments:

20ml of hot water at 60 °C, 80 °C and 100 °C was poured over the seeds.

ix) Scarification:

Under the view of a dissecting microscope the testa of each seed was scratched with a needle, near the end opposite the radicle.

x) Potassium nitrate:

20ml of 0.2% Potassium nitrate (KNO<sub>3</sub>) solution was added to the filter paper, instead of water, prior to seed placement.

xi) Stratification:

Seeds were placed on water moistened filter paper as above, petri dishes wrapped in aluminium foil and placed in a refrigerator at approximately 6°C (+/-2°C) for 48 days. They

were subsequently placed in the germination chambers at control conditions for 29 days and then a constant 20 °C incubator for an additional 21 days.

xii) Fruits:

Fruits with potentially viable seed were relatively obvious as they were firmer and wider and had spreading sepals when compared to unfertilized flowers or fruits with nonviable or damaged seeds.

Selected fruits were tested under otherwise normal control conditions. Any ungerminated fruits were opened and checked that they contained potentially viable seed.

*Data analysis*

The rate of germination was compared between each treatment and the control using the coefficient of the rate of germination (CRG) devised by Bewley and Black (1994). CRG is defined as:

$$\text{CRG} = \text{total } n / \text{total } (t \text{ } n) \times 100\%$$

Where:  $t$  is the day when germination was counted beginning from day 0 (day of sowing)

$n$  is the number of germinated seeds on day  $t$

Germination was considered to have commenced for a treatment when germination was observed in at least half of the replicates ( $\frac{1}{2} n$ ). This avoided the bias of recording germination commencement should one or two seeds have germinated well before the main trends. A one-way analysis of variance within 95% confidence limits, was conducted using Analyse-it statistical package within Microsoft Excel to determine any significant differences between rates of germination. The hot smoked water treatment was excluded from calculations to avoid bias due to the low overall rate of germination and fungal destruction of seeds.

*3.2.5.2 Soil seed bank*

In order to examine persistence of seed in the soil, a variation of the method used by Lunt (1995) was employed. A pooled sample of fruits (seeds in persistent calyx) was collected from the main

study area in late February/ early March 2000 and stored at ambient temperature in brown paper bags until used. 32 pouches (45x55mm) were made from 1.5x1.8mm nylon mesh ('fly-screen') and 25 fruits were placed in each pouch which were then sealed with fishing line and a layer of permeable polyester nylon shower screen material attached to the underside to prevent the contents falling out. On the 17<sup>th</sup> March 2000, the pouches were randomly allocated a position for burial within a 4m x 4m plot within the unlogged control area of the study site. Several existing *Brunonia* plants were observed growing in the plot. Each pouch was buried approximately 4cm deep and the location identified with a steel peg.

After 2,4,8 and 12 months, 8 pouches were to be randomly selected for removal. Due to a high germination percentage in the 8 pouches checked on May 17<sup>th</sup>, a further six were retrieved on May 19<sup>th</sup> and, as they showed the same trend, the remainder were retrieved on May 31<sup>st</sup> (<65 days). The calyx of each ungerminated individual was removed to determine its fate with the aid of a dissecting microscope. Germinants or destroyed seeds were counted and ungerminated potentially viable seeds were placed on moist filter paper in a sealed petri dish in natural light for 45 days to see if they subsequently germinated.

Concurrently, on the 17<sup>th</sup> March, six petri dishes of 25 fruits each were established to determine the germinability of the collected seeds in relatively controlled conditions. Fruits were placed on filter paper, sprayed with Benlate (1g/l), the petri dish sealed and left in a sunny position at room temperature. The dishes were checked every 5-6 days for 53 days and the germinants counted and removed. The filter paper was remoistened as required. Ungerminated seeds were tested for potential viability by squashing.

### **3.3 Results**

#### **3.3.1 Flowering phenology**

##### *3.3.1.1 Population flowering phenology*

Earliest observed flowering in the field, for any year, was on 16 November 2000 at "Emu Plains" on the Powranna Road south of Perth with numerous plants in flower in a very open and sunny position. Propagated plants growing in a glasshouse in Launceston were recorded flowering well on 16

October 2000. Latest observed flowering in the field was for a single plant growing in scarified soil at the main Bracknell study site on 3 March 2000. One propagated plant growing in a pot outdoors was observed flowering as late as 25 April 2001. During the individual flowering period study at the Bracknell study site (below) general observations of the population indicated first flowering on 20 November 1999 (-4 days). Last flowering was noted on 3 March 2000 (+4days) giving an estimated absolute period of approximately 104 days although the bulk of the population flowered over a much shorter period as indicated by sampled plants (65 days).

Figure 3.1 displays the trend of flowering for a total of 279 rosettes or approximately 114 plants in the eighteen 1x1metre plots on the Bracknell site during 2000/2001. The number of rosettes with flowers is also depicted. On average, each plant contained approximately 2.4 rosettes (279 rosettes for 114 plants). The maximum number of flower heads recorded on any one rosette was three (9%) while a single flower was most common (58%).

Flowering in plots commenced on about 17 November 2000 and was finished by 6 January 2001 giving a maximum flowering period of 51 days that season. Numerous flower heads were grazed by native animals or rabbits in four plots between 9-17<sup>th</sup> of December possibly reducing the recorded population flowering period in 2000/2001. The maximum flowering period for the previous year was approximately 65 days for sampled plants.

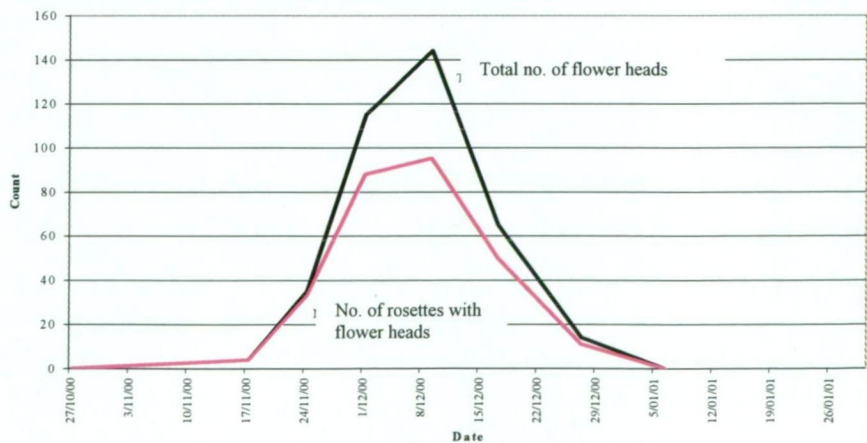
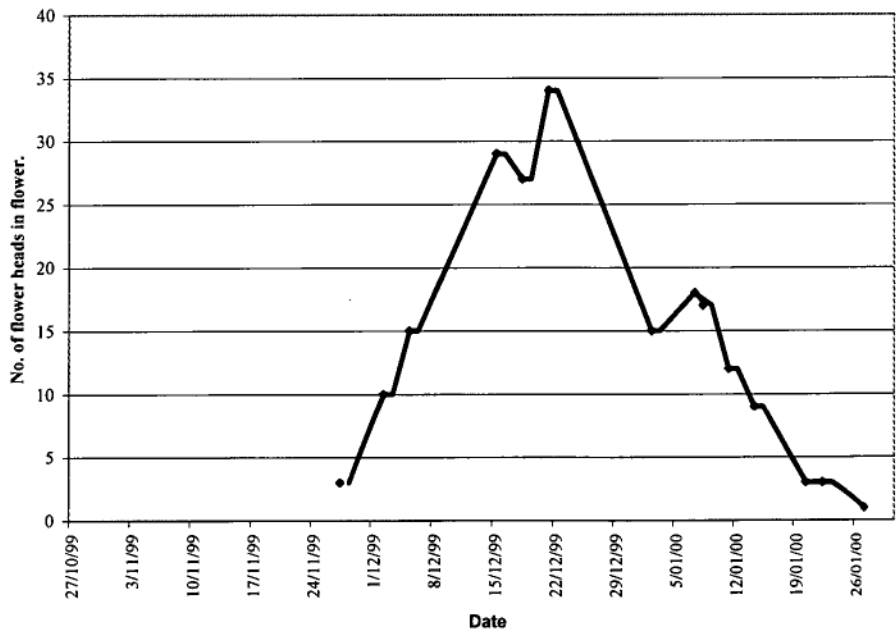


Figure 3.1: Flowering trend of *Brunonia australis* at Bracknell 2000/2001



Peak flowering period was between 1 December and 9 December with up to 144 flowers observed in the plots on 9 December. This compares to the peak flowering around 21 December for fewer plants in the individual flowering period study in the previous year (1999) (Fig. 3.2). Rainfall during spring was well below the long-term average in 1999 but was slightly over the average in 2000.

Observations at various populations in 2000 indicated that flowering was earlier and generally more profuse in sunny situations. Part of the Powranna population in the Midlands was flowering well in Mid-November on a westerly-facing slope in an area once cleared for gravel that had limited tree cover. The trend was best displayed at the Riverside population near Launceston where prolific flowering of *Brunonia* was observed on the northern property boundary, which adjoins open farmland. The general density of *Brunonia* and its flowering vigour was noticeably lower in the more shaded, forested areas away from the pasture edge.



**Figure 3.2:** Flowering trend of *Brunonia australis* at Bracknell for plants used in the individual flowering period study 1999/2000.

The flowering periods of *Brunonia* recorded in the literature are summarized in table 3.1.

**Table 3.1:** Season of flowering for *Brunonia australis* recorded in the literature.

<i>Location</i>	<i>Flowering period</i>	<i>Author</i>
General reference	winter and spring	Carolin (1992a)
NSW	“usually spring”	Carolin (1992b)
ACT (andNSW)	spring	Eddy <i>et al.</i> (1998)
QLD	“mainly spring-summer”	Stanley and Ross (1986)
NT	August-November	various herbaria
WA	May to October	FloraBase (1999)
WA	August and September	Gardner (1972)
WA	late winter and Spring	Mueller <i>et al.</i> (1994)
WA (Kimberley)	June and August	Wheeler <i>et al.</i> (1992)
Victoria	summer	Fuhrer <i>et al.</i> (1975)
Victoria	Nov-Dec (Oct-Jan)	Ewart (1930)
Victoria	November-January	Cochrane <i>et al.</i> (1973)
SA	September-November	various herbaria
Sthn Victoria	late spring	Dunn and Rennick (1990)
SE Australia	October-February	Marriott and Marriott (1998)

Potentially ripe seed of *Brunonia*, as determined by propagules readily falling from seed heads, was observed occurring as early as late January and were regularly noted in February and March.

### 3.3.1.2 Individual flowering

Of the 56 flower heads studied to determine individual inflorescence flowering, 10 flower heads were lost to grazing by native animals or rabbits.

Figure 3.2 depicts flowering trend. The peak flowering period was around 21 December with 34 heads recorded in flower. It was noted as a period when many of the earlier flowers were finishing and the later ones beginning.

The average flowering period for 28 flower heads was 19.1 days (SD +/-4.0). The longest certain flowering period for an individual flower head was at least 26 days (+8) for one flower and 25 days (+8) for another. The shortest certain flowering period was 13 days (-4). Taller and larger flower heads tended to flower longer than smaller ones (as would be expected).

### 3.3.1.3 Flowering fecundity

The potential number of florets per inflorescence was 77 and 89 in two representative *Brunonia* inflorescences (Table 3.2).

**Table 3.2:** Floret number in two representative *Brunonia* inflorescences.

	Sample 1	Sample 2
Date collected	5/12/1999	19/12/1999
Diameter of inflorescence (mm)	20	20
A. No. of current flowers	45	41
B. Buds imminently flowering	20	14
C. Other developing buds	24	22
D. Apparently nonviable or very young buds	6	0
<b>Total of viable buds and flowers</b>	<b>89</b>	<b>77</b>

The range in expected total number of florets per inflorescence was 45 (17mm diameter inflorescence) to 108 (21mm diameter inflorescence) with an average 59 percent successful fertilization rate (Table 3.3). No trials specifically addressed the successful development of inflorescences but 18% of flagged inflorescences were removed before seed set by grazing in the Bracknell study site in 1999/2000.

**Table 3.3:** Fertilization success and fecundity of *Brunonia* inflorescences (n=18)

	Inflorescence diameter (mm)	Calyx with seed	Calyx without seed	No. apparently missing	Expected total no. of florets	% potentially viable seeds
Mean	20	42	28	1	71	59
St Dev.	1.6	11.0	12.2	1.4	16.7	11.4
Range	17-23	n/a	n/a	0-4	45-108	40-75

### 3.3.2 Invertebrate Pollination

Eleven insect pollinators were observed on *Brunonia* inflorescences including four beetle species, three fly species, three native bees and the introduced honeybee (Table 3.4).

**Table 3.4:** Invertebrate species observed on *Brunonia australis* flower heads.

Family	Genus/species	Description	Location/date	Activity
Mordellidae	<i>Mordellastena</i> sp.	Pin-tailed beetles	Bracknell, Nov.99	Numerous, crawling in and out of flowers
Oedemeridae	<i>Ischnomera</i> sp.	Beetle	Bracknell, Nov./Dec. 1999	Very numerous, active over flower heads.
Scarabaeidae	<i>Phyllotacus rufipennis</i>	Beetle	Bracknell, Dec.99	Fossicking on flower head
Cleridae		Beetle	Westwood, Dec.2000	Flying between flower heads
Bombyliidae	-	Beefly	Bracknell, Dec.99	Fossicking on flower head
Calliphoridae	-	Blowfly	Bracknell, Nov.99	Motionless on flower head
Syrphidae	( <i>Melanostoma</i> sp.?)	Hover fly	Blackwood Ck. Jan.99 Bracknell, Nov.99	Regularly seen at different locations fossicking on flower heads
Halictidae	<i>Lasioglossum</i> sp.A	Native bee	Bracknell, Dec.99	Very actively collecting pollen
Halictidae	<i>Lasioglossum</i> sp.B	Native bee	Bracknell, Dec.99	Very actively collecting pollen
Halictidae	<i>Lasioglossum</i> sp.C	Native bee	Blackwood Ck. Jan.99	Fossicking on numerous flower heads.
Apidae	<i>Apis mellifera</i>	Honeybee	Westwood, Dec.2000	Fossicking on numerous flower heads.

**3.3.3 Seed dispersal**

**3.3.3.1 Wind**

The constant descent velocities (F) in table 3.5 were based on the mean of each experiment rather than the absolute maximum fastest falling or the minimum slowest falling fruit. If the minimum slowest falling fruit were used, the overall estimated distance of dispersal at each wind strength would be approximately 10% greater which, under normal conditions, is a matter of centimetres (Table 3.6).

**Table 3.5:** Constant descent velocity (F) for *Brunonia* fruits based on fastest, slowest and average fall over 5 m.

	Experiment 1 –fastest	Experiment 2 – slowest	Experiment 3 -average
n=	8	9	12
Average descent time (s)	2.08	3.23	2.49
Stddev	0.17	0.43	0.26
m/sec (F)	2.40	1.55	2.01

**Table 3.6:** Predicted wind dispersal of *Brunonia* fruits from a 30 cm high seed head using average F value for fastest, slowest and average timed seed falls.

Wind strength			Average Dispersal (metres)		
km/hr	m/s	Beaufort scale	Fastest Falling	Slowest falling	Average falling
5	1.39	Light air	0.17	0.27	0.21
10	2.78	Light breeze	0.35	0.54	0.41
25	6.94	Moderate breeze	0.87	1.34	1.04
40	11.11	Strong breeze	1.39	2.15	1.66
70	19.44	Gale	2.43	3.76	2.90
80	22.22	Strong gale	2.78	4.30	3.32
100	27.78	Storm	3.47	5.38	4.15

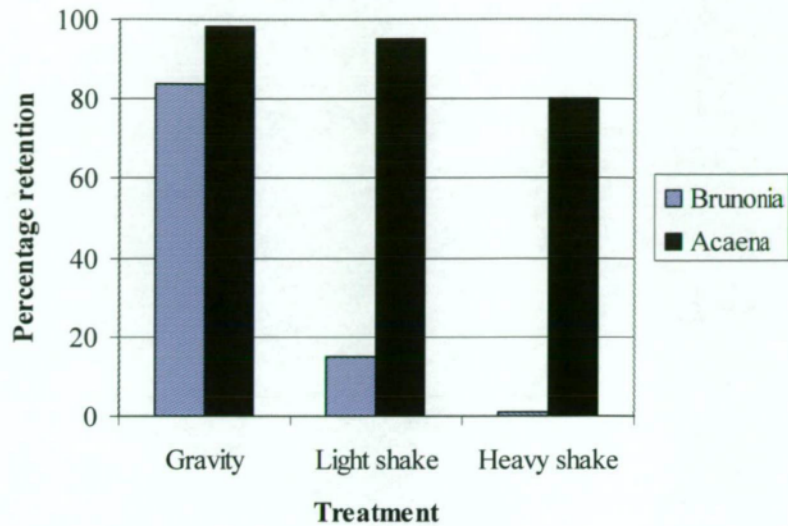
The average weight of *Brunonia* fruits was calculated at 3.0 mg. Average weight of seeds was 1.7 mg. This compares to an average weight of fruits measured by Morgan (1998) of 2.86 mg and by Pyrke (1994) of 2.89 mg.

### 3.3.3.2 Dispersal by animal

Dragging a wallaby fur across *Brunonia* heads did not result in mass attachment of fruits. The most fruits that attached to the fur was 12 out of an estimated 100, and only six remained after a light shake of the skin. It was noted that one or two fruits occasionally remained in the fur despite a reasonably vigorous shake of the skin.

Under the more controlled condition of running a seed head along the skin by hand, similar results were noted with perhaps a slightly higher proportion being retained at each stage. Generally, between one and four fruits of an estimated 25-30 remained on the fur despite the vigorous shake.

*Brunonia* is significantly less adhesive than *Acaena* at ( $\alpha = 0.05$ ) for each treatment (Fig. 3.3), which remain well attached despite a reasonably vigorous shake of the skin.



**Figure 3.3:** Mean percentage retention of fruiting bodies on a Bennetts Wallaby fur for *Brunonia australis* and *Acaena novae-zelandiae*

### 3.3.4 Germination

#### 3.3.4.1 Laboratory germination tests

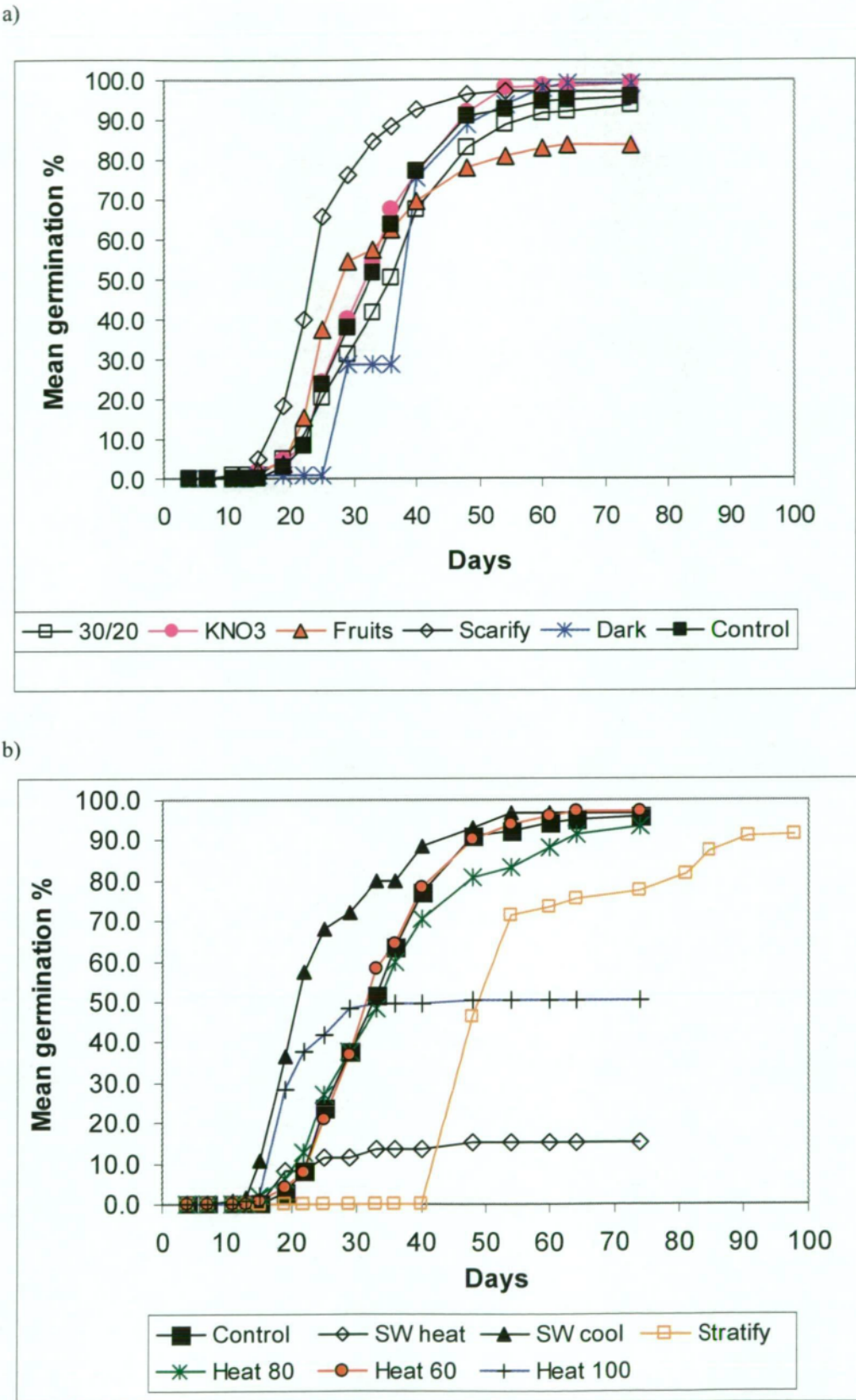
Mean total germination (Table 7; Fig. 3.4) was very high in all treatments (>80%) except for those where seed was damaged by fungal attack (smoked water treatments) or excessive heat (heat 100). The cool smoked water treatment had high total germination (99%) for the 65% of seeds that avoided fungal attack. Germination commencement was relatively uniform in all treatments at 15-22 days (Table 3.7). Figure 3.4 indicates absolute commencement and completion for all treatments. There was a significant difference ( $P > 0.05$ ) in the rate of germination between three treatments and the control (Fig. 3.5). Scarification, 100-degree heat (heat 100), and the cool smoked water (SW cool) treatments had significantly higher rates of germination compared to the control. The stratified treatment appeared to have a slower rate of germination (Fig. 3.5) when compared to the control over the exact same period but as germination commenced while the seeds were receiving the chilling treatment, a relevant statistical comparison could not be made. The results indicate that stratification is clearly not required for germination.

**Table 3.7:** Germination characteristics of *Brunonia australis* under 12 treatments.

Treatment	Control	30/20	KNO3	Fruits	Scarify	Dark	SW heat	SW cool	Heat 60	Heat 80	Heat 100	Stratify
Mean %germ.	95.7	93.7	99.2	83.9	97.2	99.3	42.3	99.0	97.2	93.3	50.2	91.7
SE	1.6	1.7	0.8	2.7	1.8	0.7	20.6	0.9	1.4	2.2	10.2	3.2
n=	6	6	6	6	6	6	5	8	6	6	6	6
Mean no. days to 50% germ.	33	39	33	31	25	(40)	-	23	33	35	23	51
SE	0.9	2.0	1.3	2.1	1.1	0.0	-	1.0	1.1	0.7	1.0	1.3
n=	6	6	6	6	6	6	-	6	6	6	3	6
No. days for $\frac{1}{2}n$ to commence germination	22	19	19	15	15	?	-	15	19	15	19	?
No. days for $\frac{1}{2}n$ to complete germination	54	54	54	54	40	54	-	48	54	54	29	85

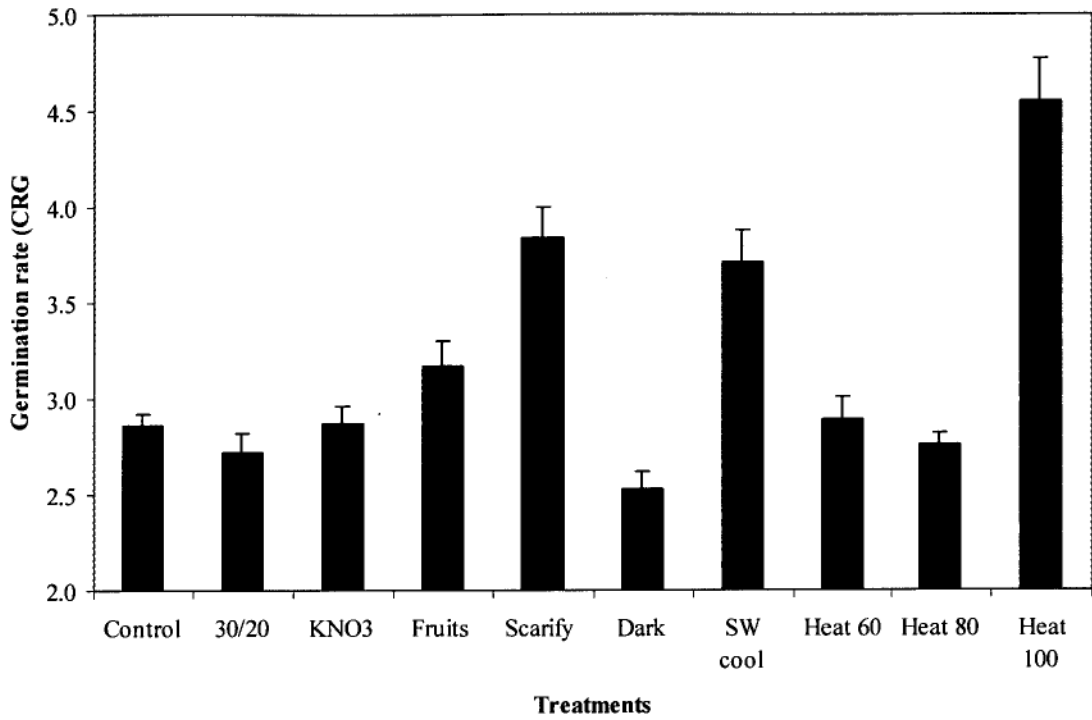
The first evidence of germination in the logged/scarified treatment was typically the emergence of large green cotyledons that pushed through the point of scarification with radicle formation following soon after. Generally, radicle protrusion was the first stage of germination in other treatments.

Many of the germinants of the heat 100 treatment appeared deformed with limp, browned cotyledons and swollen radicles and unlike germinants from other treatments, failed to develop further when transferred to different petri dishes for on-growing. Mean germination was also lower in this treatment (Table 3.7) with ungerminated seeds having a blackened and scalded appearance. The apparent increased rate of germination in the cool smoked water treatment is likely to be inaccurate. The high level of fungal attack (35% of seeds) is more likely to have affected those seeds that would have otherwise germinated later.



**Figure 3.4:** Cumulative germination percentage of *Brunonia australis* over time for: a) six treatments and, b) temperature and smoked water treatments.





**Figure 3.5:** Rate of Germination (CRG) of *Brunonia* seeds under 10 germination treatments.

#### 3.3.4.2 Soil seed bank

*Brunonia* seeds do not appear to persist in the soil as a seed bank. In this trial, designed to test viability over a 12 month period, 98% of seeds had either germinated (81%) or were non viable (19%) after two months in the soil. Very few seeds (1.4%) appeared to be potentially viable after two months in the soil and, of these, only two seeds subsequently germinated in the petri dishes.

The majority (81%) of non-germinated seeds appeared to have been consumed by various soil micro-fauna. Several translucent 1 mm long worms (nematodes?) and translucent, beige coloured mites were observed in eaten out seeds. What appeared to be a large number of eggs were observed in the eaten out shell of one seed. Only 1% of seeds could not be accounted for.

### 3.4 Discussion

This study has detailed the main elements of the reproductive ecology of *Brunonia australis* both for a single population near Bracknell, Tasmania and more broadly across other populations in the State. The species flowers predominantly in December with individual flowers lasting on average nearly three weeks at the Bracknell study site in 1999. A range of insect pollinators was recorded for the species and a fertilization success of 59% was observed at the Bracknell site in one year. Dispersal of fertilized propagules appears to be limited, with wind unlikely to move them more than a few metres under normal conditions, and successful attachment to animal fur a low probability. Neither does the species have any apparent seed dormancy mechanism, germinating readily under a range of experimental conditions and in the soil. *Brunonia* seed is unlikely to be retained in a soil seed bank with almost 98% of seeds germinating or becoming unviable after only two months during an experiment at the Bracknell site. Poor dispersal ability and effective germinability may help explain why the species is often seen growing in dense clusters.

#### 3.4.1 Flowering phenology

The average length of flowering (anthesis) for individual inflorescences (that consist of approximately 70 florets) of *Brunonia* was found to be about 19 days at the Bracknell study site in 1999. It is a late spring and early summer flowering species with a peak period of early December in 2000. Overall flowering period generally extends from late October through to about March. Peak flowering may vary between populations in any year, apparently due to openness in habitat and possibly rainfall, but in most years would fall within the period one week either side of December.

During the 2000 study on population flowering period, flowering in the selected 18 plots reflected the phenology of the wider population in the study area. While possibly starting just over a week or so later, the flowering period in the preceding year (1999/2000) was longer, having extended into late January as observed in the individual flowering period study. The difference is likely to have been caused by better spring rains in 2000, which permitted good and consistent early growth, and very dry and hot conditions throughout December and January 2001, which restricted any further flower development (Bradstock 1989). Rainfall in spring 1999, in contrast, was well below the long-

term average by up to 30mm per month and slower development may have been reflected by a more protracted flowering period. Early and profuse flowering was clearly observed in other populations in sunny positions in 2000, with more shaded parts of the same areas not flowering as well. *Brunonia* will flower under some cover, including bracken and shrubs, but field observations indicate an obvious preference for open sunny positions.

Possibly due to the same differences in seasonal weather discussed above, the peak flowering time in 1999 appeared to be up to two weeks later than 2000. The biases of the 1999 study, where the individuals chosen for observation had already started flower stalk development, do not allow a definitive comparison of these observations. Peak flowering in a particular population is likely to vary from year to year depending on growing conditions but in most areas will occur sometime in December.

The flowering period of individual flowers is dependent on many factors, particularly environmental variables such as day length and temperature (Raven *et al.* 1982). Evidence for variables controlling timing of *Brunonia* flowering in the literature is inconclusive with Western Australian, New South Wales and Queensland records indicating mainly winter and spring flowering while Victoria and Tasmania flowering mainly in late spring and summer. Clarke (2000) proposes that the main cue for flowering in temperate Australian woodlands is probably photoperiod. A single two-year-old potted plant beneath an outside light in Tasmania was observed to develop a flower shoot in July suggesting that photoperiod is more critical than temperature for initiating flower development but additional studies would be required to confirm this. It is speculated that following photoperiodic initiation of flowering, subsequent growth and development then relies more on temperature, rainfall and other growing conditions.

Timing of flowering for individual plants may also vary according to timing of germination. Observations on seeds sown in pots in autumn and winter have shown that a proportion of *Brunonia* plants will flower in the first season of growth as noted by other authors (Delpratt 1996). Failure to flower in the first season may be due to a late spring or summer sowing time (McAllister 1998), as

plant development is typically slow in anything less than ideal conditions (Hitchmough *et al.* 1989). There is also the possibility of a vernalisation (chilling) requirement for floral initiation. Most germination in the field occurs before spring allowing adequate time for flowering in the first year given good growing conditions.

In the assessed field trial, inflorescences that reached seed set had an average 42 viable propagules (59% successful fertilization) which is comparable to that in Delpratt (1999 unpubl.) who found averages of 43 (range 20-69) and 30 (range 9-46) propagules in two harvests of cultivated plants. This possibly reflects the ubiquity of insect pollinators (discussed below). In the wild, a single plant may have three to four flowering stems, or more depending on its degree of additional rosette growth, and an estimated 100-200 plus seeds may be produced per plant. Fuss (1998) found between five and 27 blooms occurring per plant in Western Australia. Many populations in Tasmania, however, appear to produce only one or two inflorescences per plant and estimates of less than 100 seeds per plant is likely to be more typical.

#### 3.4.2 Invertebrate pollinators

Eleven species of insect pollinators were observed on *Brunonia* inflorescences, including: four beetles, three fly species, three native bees and the introduced honeybee. The Hover Flies were the most commonly observed insects on *Brunonia*, at numerous locations. Colless and McAlpine (1970) suggest they are of likely importance as pollinators of plants, probably as they transfer between flowers for feeding on nectar and other plant secretions (Zborowski and Storey 1995). Hover Flies were also observed visiting potted *Brunonia* plants in a suburban garden in Launceston, Tasmania. The other flies (Beefly and Blowfly) are also known to feed on flowers (Goode 1980) but were seen infrequently on *Brunonia* during surveys.

Other important pollinators of *Brunonia* appear to be native bees in the family Halictidae. All bees rely on nectar and pollen as their primary food source (Michener 1970) and large quantities of pollen, presumably from *Brunonia*, was observed on the rear legs and abdomens of individuals caught visiting *Brunonia*. The honeybee (*Apis mellifera*) was only observed at a distance and could

not be checked for pollen. Honeybees are known to have strong attraction to violet and blue colours (Meeuse 1984) as seen in *Brunonia*, and are thus likely to play a role in pollination.

The role of beetles in pollination of flowers is uncertain, although some species are known to feed on nectar and, therefore, probably play some part (Zborowski and Storey 1995). Beetles from the families Oedemeridae and Mordellidae were commonly found moving actively within *Brunonia* flower heads and the former were capable of fast movement to other heads upon being disturbed. Beetles often eat plant matter in both adult and larval stages so it is unclear to what degree their relationship with *Brunonia* is beneficial. Their ability to move between flowers suggests they may act as pollination vectors.

*Brunonia* is listed as a food plant for butterflies on a University of Melbourne web site (Burnley 2000). No butterflies were recorded on *Brunonia* during any field trips and only one small, unidentified moth was observed on a flower in a single location. The general form and colour of the inflorescence is typical of flowers that may be visited by moths and butterflies (Meeuse 1984) but no further data are available.

Peacock and Smith-White (1977) show that *Brunonia* has a strong self-incompatibility system throughout diploid populations. Tetraploid populations of *Brunonia* do not appear to have a self-incompatibility system but may not be as widespread, being only known from one population in Tasmania (Peacock and Smith-White 1977). The importance of a strong pollination vector as provided for by insects reduces the likelihood of inbreeding depression in the diploid populations. Small diploid populations however, would have difficulty increasing through seed recruitment. This has been observed in glasshouse plants by the author, in horticultural situations (Will Fletcher, pers. comm.) and in isolated experimental plantings (Peacock and Smith-White 1977).

The importance of insect pollination of *Brunonia* is confirmed in its use of secondary pollen presentation (Howell *et al.* 1993). In this system, pollen is deposited into the stylar cup (indusium) prior to anthesis (Leins and Erbar 1989). The self-incompatibility system and late maturation of the

stigma prevents self-pollination (Carolin 1960; Howell *et al.* 1993). Secondary pollen presentation is seen as an adaptive advantage where probability of cross-fertilization by visiting insects is improved due to the increased proximity of pollen to the stigmatic surface (Howell *et al.* 1993). Carolin (1960) further suggests that the structure of the indusium allows accurate deposition of pollen onto insects and that subsequent collection of pollen onto the stigmatic surface of older, receptive flowers is assisted by special pollen collecting hairs on the indusium.

The role of the indusium has also been suggested as important for timed release of pollen to match availability of preferred pollinators and avoid unwanted visitors, or for pollen protection from abiotic elements such as rain, allowing dry climate species (like *Brunonia*) to move into wetter environments (Carolin 1960).

While there is increasing concern about widespread human-induced collapse of pollination systems (Johnson and Steiner 2000), species relying on a broader range of pollination vectors are more likely to be resilient to ecosystem change than those with a high degree of specialization (Johnson and Steiner 2000). Evidence suggests that *Brunonia* has a range of insect vectors for pollination and that this aspect of its ecology is not a limiting factor in the long-term viability of populations. The self-incompatibility system may play a role in the demise of smaller populations but may also limit inbreeding effects.

Only observation-based daytime surveys were conducted in order to obtain a general understanding of insect visitors to *Brunonia* flower heads. A more detailed survey may have included sticky traps and other night based surveys but this was considered unnecessary in the context of this study.

### 3.4.3 Seed dispersal

The shuttle-cock like indehiscent fruit of *Brunonia* is the main dispersal unit and this study has found that they are not especially adapted for wide dispersal by either wind or animal vector. The fanned appearance of the persistent calyx suggests wind-borne dispersal while its hairiness implies

an ability to be dispersed by animals. Blombery (1967) suggests that the fruit simply falls from the plant when ripe.

Greene and Johnson (1989) calculated F values for winged seeds of *Pinus contorta* at 0.61m/s, *Fraxinus americana* at 1.42m/s, *Acer negundo* at 0.80m/s and *Tragopogon dubius* at 0.40m/s. They also reported the F values of 12 species calculated by Kohlermann (1950) as ranging from 0.55 to 1.49 m/s. *Brunonia* fruits are not winged (Carolin 1977), are relatively heavy at 3mg and in contrast fell relatively quickly. The average F value of the slowest falling fruits was 1.55m/s. The overall average was approximately 2m/s. From a height of 0.3 m, less than an estimated 6 m would be obtained under unlikely strong winds of 100km per hour for the slowest falling fruits. In experiments on perennial grassland species van Dorp *et al.* (1996) calculated dispersal distances for similarly heavy seeds, in winds below 14m/s (50km/hr), approximately equivalent to those determined in this study but above 14m/s distances were exponentially greater. Dispersal distances at the higher wind speeds may be under estimated in this study. Like *Brunonia*, the species used by van Dorp *et al.* (1996) lacked seeds with special adaptations for wind dispersal.

Winds over 50km/hr would be rare near ground level (0.3-0.4m) in dry sclerophyll forests and the results suggest that *Brunonia* does not rely on wind for dispersal to any great distance. Pyrke (1994) found only 3.2% of 157 seedlings of *Brunonia* more than 0.5metres from an adult plant that had flowered the previous year and 70% were within 0.3metres. The estimates of the present study do not take into account any ability to continue being blown once on the ground. While this may play a part in open areas of bare soil it is likely to be limited in typical situations where fruits would get caught in vegetation, litter, rocks or other ground material.

Results from experiments with the wallaby skin are inconclusive but indicate that animals may transport small numbers of *Brunonia* fruits for unknown, but probably relatively short, distances. *Brunonia* does not appear to have any specific adaptations for adhesion. The persistent receptacle and calyx are covered with dense silky hairs, which aid some attachment, and Carolin (1966) briefly speculates this is important for dispersal. These hairs however, are not typical of adhesive fruits,

which normally employ barbs, hooks or viscid outgrowths (Sorenson 1986). The experiments with the wallaby fur support this contention with the *Brunonia* dispersal unit being significantly less effective catching on the fur than that of a known adhesive species, *Acaena novae-zelandiae* (buzzy). The methodology for determining seed dispersal by adhesion to animals is as varied as the range of dispersal units and animal vectors (e.g. Bullock and Primack 1977; Sorenson 1986). The enormous logistical effort required to quantitatively analyse plant-animal interactions has limited the availability of comparative data in the area of adhesion. The many variables that influence successful dispersal such as chance of attachment, the probability of seeds falling in suitable habitat and the seasonal abundance of the dispersal vector are also difficult to take into consideration (Bullock and Primack 1977; Higgins and Richardson 1999; Nathan and Muller-Landau 2000). Cain *et al.* (1998) suggest that the majority of woodland herbs do not have adaptations that allow effective long distance dispersal by wind, adhesion (to animals) or ingestion.

Various other mammals may also transport *Brunonia* seeds. Echidnas and Tasmanian bettongs are common in grassy dry sclerophyll forests. Echidnas, or evidence of them, were regularly seen during surveys of *Brunonia* populations across Tasmania. As ripe fruits of *Brunonia* readily fall from seed heads when bumped, it is conceivable that they could lodge onto the backs of echidnas as they move through a population and be transported some distance from the parent plant. One echidna at the Bracknell study site was observed to have dandelion (*Taraxacum officinale*) dispersal units in its fur and when *Brunonia* fruits were dropped onto its back many of them sat firmly amongst the spines and fur. Even if such means of successful dispersal are rare, Higgins and Richardson (1999) argue that uncommon events, including extraordinarily strong winds, are more important in plant migration rates than has been previously considered.

It is unlikely that *Brunonia* relies on ingestion and defecation by animals as a means of dispersal as the seed coat is soft and the seed easily crushed. Ants are a major vector for the dispersal of many plant seeds (Stiles 1992; Clarke 2000) but the distances moved are rarely greater than a few metres (Cain *et al.* 1998). Further research is required to determine whether ants have a role in dispersal of *Brunonia* seed.



The availability of fruits for dispersal off the seed heads, by various means, may be influenced by the frequency and intensity of rainfall events during the ripening period in late summer and early autumn. On several occasions following rain events, the availability of ripe fruits was severely depleted as they were presumably knocked off heads by raindrops.

#### 3.4.4 Seed germination

*Brunonia* seed collected from the field has a high degree of viability without any apparent dormancy mechanism. All treatments in this experiment yielded mean germination levels of greater than 80% except where seeds were mechanically damaged by excessive heat or fungal attack. The rate of germination (CRG) was significantly faster in the scarification treatment and possibly in the cool smoked-water and 100 degree heat treatments though these were affected by high seed losses.

Germination success reported in the literature is mixed. Most authors indicate ready germination for the species (Blombery 1967; Morgan 1998; Hitchmough *et al.* 1989; McAllister 1998; Fuss *et al.* 1996; Delpratt 1996), but others report very poor or even no germination (Hamilton 1913; Fuss *et al.* 1996; Peacock and Smith-White 1977). As the results of Fuss *et al.* (1996) vary between commercial seed sources, it is possible that there are differences in seed viability between populations. Age or storage conditions may also have contributed to seed viability with the main problem source reported as being nine years old at the time of the experiment.

While dormancy in *Brunonia* is not typical, Fuss *et al.* (1996) reported a significantly poorer (nil) germination response in the presence of the plant growth hormone benzylaminopurine (BAP). BAP is a synthetic growth hormone unlikely to occur naturally in plants (Raven *et al.* 1982) and thus the effects are irrelevant to the germination ecology of *Brunonia*. Of course a range of other natural inhibitors such as pH levels, the presence of certain organic chemicals in soils, or physiological responses to various elements of the environment, may restrict plant germination (Ketring 1973). Any such conditions, however, are external to the seed and do not reflect an in-built dormancy mechanism.

Two of the treatments that significantly increased the rate of germination, heat 100 and scarification, may have resulted from the cracking of the seed coat thus freeing any restrictive effect of the coat or allowing faster water uptake or gaseous exchange to occur (Ballard 1973; Bewley and Black 1994). Once the large cotyledons of the scarified seeds broke through, the seed coat was quickly shed. The inability of further development in germinants from the heat 100 treatment and the overall lower percentage germination suggests that such heat is detrimental. The hot smoked water treatment produced similar effects although the fungal infestation, in spite of sterilisation precautions, clouded any trends. Unlike hard seeded species, the thin seed coat of *Brunonia* (Carolin 1966) is unable to withstand extremes of heat and does not require scarification for improved germination percentage.

Responsiveness of *Brunonia* to smoke treatment has been reported in trials in Western Australia (Ag West pers. Comm.) and by the makers of the commercial smoked water treatment Regen 2000 Smokemaster (Technica Pty Ltd 2000). In the present experiment, while the rate of germination was higher, the overall germination success of viable seeds was no different between the cool smoke treatment and the control.

Hitchmough *et al.* (1989) recorded a notably rapid rate of germination in the dark for *Brunonia* although success was achieved in all light regimes. Darkness did not increase the rate of germination in this study.

Few germination results for *Brunonia* are presented in the literature. Morgan (1998) found that it took more than 28 days to achieve a mean 50% germination ( $n = 8$  replicates) which is comparable to this study where the control took approximately 33 days and the fruits treatment 31 days to achieve the same level ( $n = 6$  replicates). Given the seed weights recorded, it is suspected Morgan (1998) used seeds within the fruiting body. Overall germination however was higher in this study with the control achieving a mean percentage germination of approximately 92% after 54 days compared to only 53% in 56 days for Morgan (1998). Fuss *et al.* (1996) found a maximum germination of 69% after 44 days (observations for 56 days). A widespread species might be

expected to differ in dormancy requirements due to different ecologies but the differing results may also be related to inherent differences between seed samples or populations, varying influences within the germination cabinets or degree of seed checking prior to experimentation. The high germinability of seed from the Bracknell study area in these laboratory experiments was repeated in both the controls and treatments of the soil seed bank experiment discussed below.

Morgan (1998) recorded a lag time of 7-14 days until germination commencement compared with a minimum of about 15 days for this study. The rate of germination from this point on however agrees with the contention of Morgan (1998) and with field observations of the author and Pyrke (1994 unpubl.) that the species is an autumn germinator.

Care must be taken translating the results of laboratory germination trials to that of the field situation. The diurnally fluctuating temperatures used in all treatments, for example, were higher than that which would normally be encountered in the Tasmanian midlands during late summer and autumn, the main period of germination for *Brunonia*. Furthermore, no testing of after-ripening period was conducted. Richards and Beardsell (1987) define after-ripening as the gradual process by which seeds lose their dormancy in the dry (unimbibed) state. All seed used in germination experiments had been in dry storage for several months prior to use. While this suggests that the species has a relatively short after-ripening period, if any, (Willis and Groves 1991) other herbaceous species have been shown to have improved germination after as little as two months (Mott 1972). Delpratt (1996) found that freshly harvested seed germinated within six weeks. In Tasmania, the often-dry months of February to April may allow a short after-ripening period for *Brunonia* until it germinates in the more reliably wetter months of autumn and winter (May-August). The ability to germinate in these cooler months also supports the conclusion of no requirement for stratification.

*Brunonia* seeds are not likely to persist in the soil for more than 2-3 months. Dormancy in normal autumn-winter conditions is, therefore, likely to be very limited. This supports the results from the laboratory germination tests, which indicated there is no obvious dormancy mechanism.

It is rare in Tasmania for soil in the late autumn and winter months to be dry, so the results are expected to be a reflection of the typical response of *Brunonia* seed to burial. Some variation in germination success and timing may occur at different locations and in different soil conditions (such as pH), but the level of seed destruction through predation by soil fauna and fungal attack is likely to be the main variable. This may vary in accordance with the populations of seed predators in any year (Crawley 1992). As the area used for the trial had not been burnt for over 20 years and evidence of charcoal was minimal, it is unlikely that ash or charcoal had any influence on the results as has been shown for some species in Australian dry sclerophyll forests (Dixon *et al.* 1995; Enright *et al.* 1997; Marsden-Smedley *et al.* 1997).

Of course the ability of seeds to become buried in the first place is an important factor in determining presence in the soil seed bank. Little is known about how seeds enter the soil (Warr *et al.* 1993) however they may become buried after falling into cracks in the soil, being washed in by rain or being moved about by fauna such as ants or earthworms. As *Brunonia* tends to occur on sandy substrates in Tasmania, burial may be assisted by rainfall or trampling by animals but it is presently unknown whether burial is preferred and if so what mechanisms are important. Numerous seeds have been observed germinating and developing into adult plants in the glasshouse after being scattered on top of the soil and self-burial was not required. Other container grown plants germinated well after the seed was buried to about 5mm. Hitchmough *et al.* (1989) found that broadcast *Brunonia* seeds had a higher rate of germination and better growth than fluid drilled and slot seeded (buried) seeds although soil compaction may have influenced the latter. The evidence therefore tends towards no requirement for burial although effective germination can still occur with at least shallow burial, 4cm in these field trials.

### 3.5 Conclusion

*Brunonia australis* has an efficient reproductive ecology in Tasmania. A summer flowering species, it has a range of insect pollinators that, in this study, were found to achieve a relatively high fertilization rate of 59%. Seed viability was also found to be high (>80%) and germination

unrestricted by any dormancy mechanism. The lack of a dormancy mechanism and apparent resultant inability to maintain a seed bank in the soil coupled with a poor dispersal capability, does however, have implications for management of populations. If a population is severely depleted or removed from a site, the probability of *Brunonia* naturally repopulating the area is very low. Small populations may also be ineffective at expanding due to the species self-incompatibility system. While the vegetative longevity of the species is at least several years, constant disruption of flowering and seed production through inappropriate summer grazing, slashing or fire regimes is expected to have deleterious effects on populations in the long term. Given the status of the species as Vulnerable in the Tasmanian Threatened Species Act (1995) ongoing monitoring of flowering and seeding success is desirable at important populations.

### 3.6 Acknowledgements

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## 4. Effect of seasonal sheep grazing on the threatened herb

### *Brunonia australis* (Brunoniaceae) in Tasmania

Craig Hawkins and Dr Robert Wiltshire

**Abstract** Negative effects of grazing have often been reported for Australian native plants but impacts for some species may be more related to season of grazing than intensity. The influence of five sheep grazing regimes on the threatened herb *Brunonia australis* (blue pincushion) was investigated over a two-year period in a dry, inland *Eucalyptus amygdalina* forest in the northern Midlands of Tasmania. Six replicates of 4x4m plots were subject to summer grazing only (Oct.-Mar.), winter grazing only (Apr-Sep.), all year grazing, all year grazing and fertilizer treatment or no grazing. Winter grazing was found to be beneficial to *Brunonia*, compared to other treatments, in terms of increasing numbers of individuals and higher proportions of flowers to rosettes. Season of grazing also affected mean inflorescence height with grazing during the summer flowering period causing significantly reduced heights compared to non-grazed and winter only regimes. Results from this study suggest that long periods of either no grazing or heavy spring/summer grazing are likely to negatively impact populations due to either increased understorey competition or reduced reproductive capacity respectively. Where recent reserves have been designated over large populations of *Brunonia*, historically subject to grazing, care needs to be taken to permit a periodic winter disturbance regime that will allow the species to persist at the site. The response of *Brunonia* to various grazing regimes is expected to reflect that of many other herbs and forbs in the dry, grassy forests and woodlands of Tasmania. Land managers need to consider season of grazing, or other compatible disturbance regimes, if populations of *Brunonia* and species of similar life cycle are to be conserved.

Keywords: blue pincushion, grazing regime, dry sclerophyll forest, inland *Eucalyptus amygdalina*

## 4.1 Introduction

Grazing of domestic stock has had a significant impact on native plant abundance and diversity in Australia (Moore 1959; Kirkpatrick *et al.* 1988; Lunt 1991; Clarke 2000). Direct grazing effects have been exacerbated by the introduction of weeds and exotic animals, fertilizer use and changed fire regimes since European settlement. Broadly speaking, grazing has led to a reduction in perennial forbs and grasses and an increase in annuals and ephemerals (Williams 1969; Wilson 1990; Yates and Hobbs 1997; Clarke 2000). Nitrogen and potassium fertilizers are reported to have negative impacts on many native species in Australian grasslands and grassy forests, and favour the proliferation of environmental weeds (Moore 1959; Lunt 1991; Williams 1991). Similar impacts have been reported for other temperate grasslands (Duffey *et al.* 1974).

In some areas, however, it does not follow that a cessation in grazing would permit a reversal of these effects. Impacts on plant communities of changing established grazing regimes, including cessation of grazing, are widely discussed in the literature and an equally diverse range of trends are reported (Pacala and Crawley 1992). Many studies have shown both significant positive and negative effects on plant community floristics and structure (e.g. Ball 1974; Gibson and Kirkpatrick 1989; Gibson *et al.* 1987; Belsky 1992; McIntyre *et al.* 1995) while others show little change (e.g. Ball 1974; Lunt and Morgan 1999). Season of grazing may play an important part in determining the floristics and winter grazing in temperate regions has been reported as beneficial to many grassland dicotyledons (Duffy *et al.* 1974).

Various studies in southeastern Australian lowland grasslands and grassy woodlands and forests have shown that complete cessation of grazing has allowed more competitive species (e.g. grasses) to dominate at the expense of other species, particularly herbs (Stuwe and Parsons 1977; Dickinson and Kirkpatrick 1986; Duncan 1991). Lunt (1990) found that herb-rich woodlands in western Victoria, historically subject to grazing by European stock, were amongst the most species rich in the world. In Tasmania, grazing by domestic stock is a major influence in many grassy eucalypt woodlands and forests (Kirkpatrick and Gilfedder 1999a, 2000). Some native species in Tasmanian

grassy ecosystems are sensitive to stock grazing (Kirkpatrick 1999) and woodland remnants in good condition are often associated with absence of grazing or spelled grazing (Kirkpatrick and Gilfedder 2000). As in other parts of Australia, however, many native understorey species in these forest types require some form of periodic disturbance such as grazing or fire, for long term survival (Duncan 1999; Kirkpatrick 1999; Kirkpatrick and Gilfedder 2000). In Tasmania, Gilfedder and Kirkpatrick (1994) found an endangered daisy, *Leucochrysum albicans* preferred heavily grazed areas and declined at sites where grazing was reduced. Unlike *L. albicans*, *Brunonia australis* is palatable to stock and has been reported to be sensitive to heavy grazing (Kirkpatrick and Gilfedder 1999b) but it may also require some disturbance to persist in an area (Kirkpatrick *et al.* 1988). This anomaly and the limited and declining distribution of *Brunonia* in the dry forests and woodlands of northern Tasmania, suggests it may be a model species that reflects the responses of many native understorey herbs to grazing regimes in grassy forest/woodland ecosystems. The following study examined the short-term response of a *Brunonia* population to seasonal sheep grazing regimes and fertilizer application in a grassy forest of moderate site quality in the Northern Midlands of Tasmania.

## 4.2 Method

### 4.2.1 Study site

The study site was in a 130-hectare sheep grazing run in the Carrick area of the Northern Midlands, Tasmania (Cluan 1:25000, GR 982991). Approximately 100 hectares of the area was forested with grassy, inland *Eucalyptus amygdalina* forest and the remainder was cleared for pasture. Historically, up to 500 sheep were grazed in the area at all times of the year with occasional transfer to other paddocks. Soils were Tertiary alluvials. Apart from grazing, the forested area was subject to light firewood cutting and some areas were heavily infested with gorse (*Ulex europaeus*). Treatment plots were set up within 100 m of the grazing paddock in a grassy, forested area frequently traversed by sheep.

#### 4.2.2 Experimental design

Five treatments were applied with six permanent plots of each treatment randomly located across the study site in patches containing *Brunonia*. Plots were 2x2m with a steel star picket in each corner and fenced with 1.1m high, 150mm wire mesh caging according to the following treatments:

1. All year grazing – no fence
2. Non-grazed – fenced, closed all year
3. Winter grazed – fencing open from 1 April-30 September each year
4. Summer grazed – fencing open from 1 October – 31 March each year
5. Fertilized (all year grazed) plots – no fence

A 30cm high layer of chicken wire was installed at ground level to limit rabbit access but no covering was placed over the top to restrict possums. Plots were set up in December 1999 except the fertilizer plots, which were set up the following year on 15 September 2000. Super-phosphate (0.9.0.11) was first applied in the fertilizer treatment at an equivalent rate of 75kg/ha (80g/plot), which is an approximate standard for the area. A second application was made on 18 September 2001.

The grazing regime over the period of the study was as follows:

520 wethers 5 January 2000 – 18 December 2000

500 wethers 11 March 2001 – 19 September 2001

460 wethers 1 October 2001 – 3 January 2002

The number of *Brunonia* rosettes were counted and mapped in each plot at the commencement of the study in December 1999 and then at the changeover of the summer and winter plots on 1 October 2000 and 2001. The number of obvious new germinants were counted and mapped in 2001.

Counting was not possible at the end of the summer period due to the seasonal senescence of above ground parts. One and a half summers and two full winter periods were covered.

The numbers and heights (to nearest cm) of flowers were measured in each plot towards the end of flowering in late December 2000 and mid-January 2002.

#### 4.2.3 Analysis of data

Statistical analysis was conducted using the statistical package SPSS 10.0 for Windows.

The percentage increase in the number of rosettes (PIR) from 2000 to 2001 was calculated for each plot as:

$$\text{PIR 2000 to 2001} = (\text{no. rosettes in 2001} - \text{no. rosettes 2000}) / \text{no. rosettes in 2000} \times 100$$

A one-way analysis of variance, with a Dunnetts T3 *post hoc* comparison, was conducted to determine any significant differences between treatments for the following measures:

PIR 2000 to 2001 all plots

PIR 2000 to 2001 all plots except one abnormal summer grazed plot

Proportion of germinants to rosettes in 2001 in each plot

Proportion of flowers to rosettes (PFR) in each plot

Flower heights in 2001

#### 4.2.4 General survey of populations

During summer 2000, surveys were conducted of virtually all known *Brunonia* populations in Tasmania. Estimates were made of the number of *Brunonia* rosettes present, density and area of coverage. Landowners were surveyed for grazing data relating to stock type (none, sheep or cattle), numbers, season of grazing and the normal intensity of grazing (low, medium, high). PCord was used to conduct a Principal Coordinates Analysis (PCA) on the *Brunonia* and grazing data. The output was examined for any trends in relation to *Brunonia* density. Unusual populations, such as roadside remnants, were removed prior to the ordination. Additional analyses were conducted on only those populations that had some sheep grazing (32 populations) and on only those populations that had cattle grazing (12 populations). It should be noted that on several properties both sheep and



cattle were stocked. General observations on grazing and disturbances on all populations were also recorded.

### **4.3 Results**

#### **4.3.1 Rosettes**

The winter grazed treatment exhibited a significantly greater ( $p=0.016$ ) percentage increase in the number of rosettes from 2000 to 2001 compared to the non-grazed treatment (Fig. 4.1) ( $F_{4,25} = 6.529$ ). However, after excluding one abnormal summer grazed plot, winter grazing also exhibited a significantly greater increase in rosettes compared to summer grazing ( $p<0.05$ ). No other significant differences were noted between treatments.

The abnormal summer grazed plot had substantially more germinants (29) than any other plot in that treatment ( $\leq 1$ ). It is uncertain why this occurred but the sheep did not graze the plot as heavily as other plots open to them nearby thus allowing better flowering and seed shed. A lower grass cover in the plot may have had some influence.

Increases in rosette numbers were noted in all treatments as occurring vegetatively and through new germinants. The proportion of new germinants to total rosette numbers was significantly higher ( $p<0.05$ ) in the winter grazed treatment compared to all other treatments except the summer treatment, which had high variance (Fig. 4.3). When the obvious extreme plot was removed from the summer treatment it too was significantly different from the winter treatment (Fig. 4.3, Table 4.1). The abnormal summer grazed plot had 29 new germinants but only one other plot in this treatment had a single germinant. Only two germinants were observed in non-grazed plots (Fig. 4.2). Germinants were most abundant amongst ground moss but also appeared in areas of light litter or bare soil.

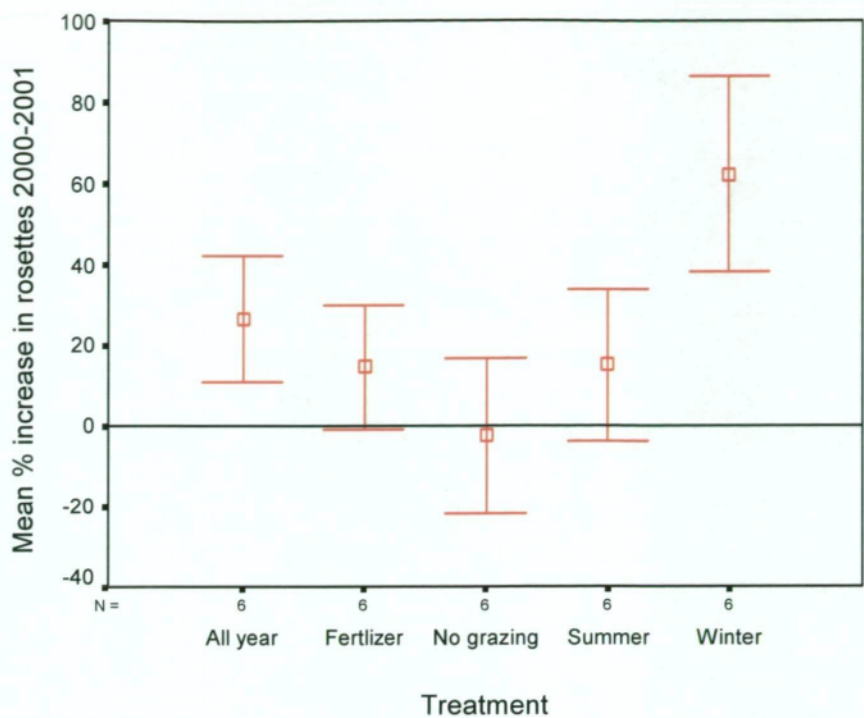
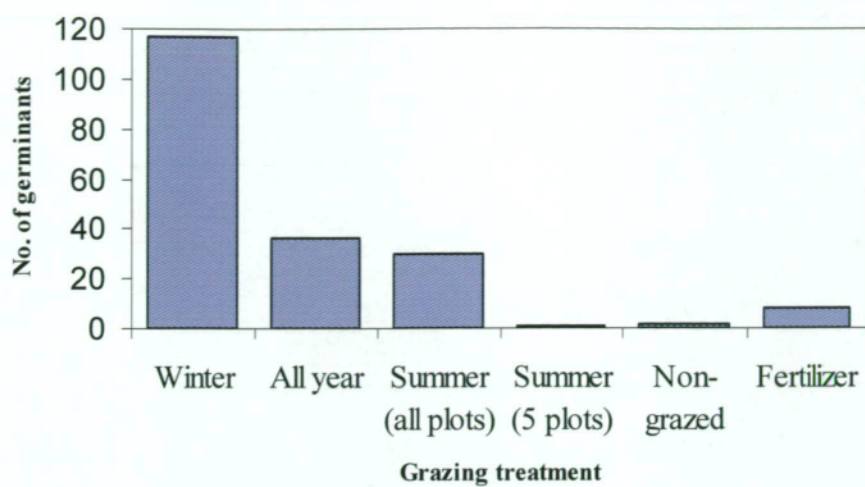


Figure 4.1: Mean percentage increase (+/- 2se) in number of *Brunonia* rosettes from 2000-2001 following five grazing treatments.

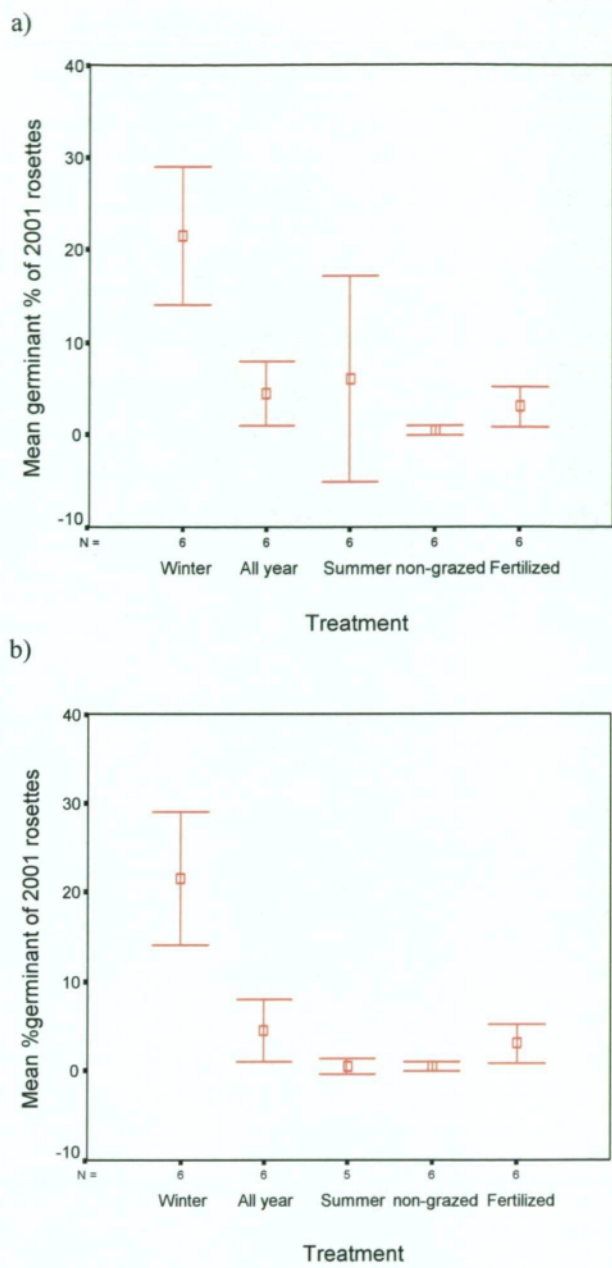
Table 4.1: Percentage germinants in total rosette count in 2001 for *Brunonia* following five grazing treatments (excluding one abnormal summer grazed plot) \*= Significant at P < 0.05.

Treatment	Mean (n=)	Std error	Significance				
			Winter	All year	Summer	Non-grazed	Fertilized
Winter	21.5 (6)	3.73	-	0.032*	0.017*	0.016*	0.022*
All year	4.4 (6)	1.73		-	0.379	0.379	0.996
Summer	0.4 (5)	0.44			-	1.000	0.374
Non-grazed	0.4 (6)	0.26				-	0.325
Fertilized	3.0 (6)	1.07					-



**Figure 4.2:** Total number of *Brunonia* germinants in 2001 following five grazing treatments.

Many rosettes were either partially or severely grazed in plots open to grazing at the time of flower observations in December and January. Occasionally whole plants were seen pulled from the ground, presumably through the grazing action of sheep.



**Figure 4.3:** Percentage (+/- 2se) of *Brunonia* rosettes in 2001 that were new germinants for a) all plots; b) all plots less one abnormal summer grazed plot.

4.3.2 Flowers

As for rosettes, the only significant differences in the proportion of flowers to rosettes (PFR) in 2001 occurred against the winter grazing treatment ( $F_{4,25} = 8.527$ ). Winter grazing allowed a higher PFR compared to all treatments except the non-grazed treatment ( $p < 0.05$ ) (Table 4.2).

The total number of flowers in each treatment for 2000 and 2001 is given in table 4.3 below. There were more flowers in all treatments in 2001 except for the fertilized treatment, which had fewer flowers. In one ungrazed plot the proportion of flowers dropped from 13 on 23 rosettes in 2000 to 0 on 12 rosettes in 2001. Thick grass was apparent in the plot.

**Table 4.2:** Proportion of *Brunonia australis* flowers to rosettes (PFR) in 2001 after five grazing treatments. \*= Significant at  $P < 0.05$ .

Treatment	Mean (n=6)	Std error	Significance				
			Winter	All year	Summer	Non-grazed	Fertilized
Winter	0.55	0.062	-	0.003*	0.013*	0.185	0.008*
All year	0.13	0.041		-	0.767	0.993	1.000
Summer	0.21	0.042			-	0.993	0.993
Non-grazed	0.28	0.079				-	0.879
Fertilized	0.16	0.037					-

**Table 4.3:** Number of *Brunonia australis* flowers in plots in 2000 and 2001 after five grazing treatments.

Treatment	Summer 2000	Summer 2001
Winter	246	337
All year	102	138
Summer	98	107
Non-grazed	85	134
Fertilized	83	57

#### 4.3.3 Inflorescence height

In 2001, mean inflorescence heights were significantly different ( $p < 0.05$ ) between all treatments except between all year grazing and the fertilized treatment (Fig. 4.4). Mean inflorescence heights, by treatment, in order of tallest to shortest were:

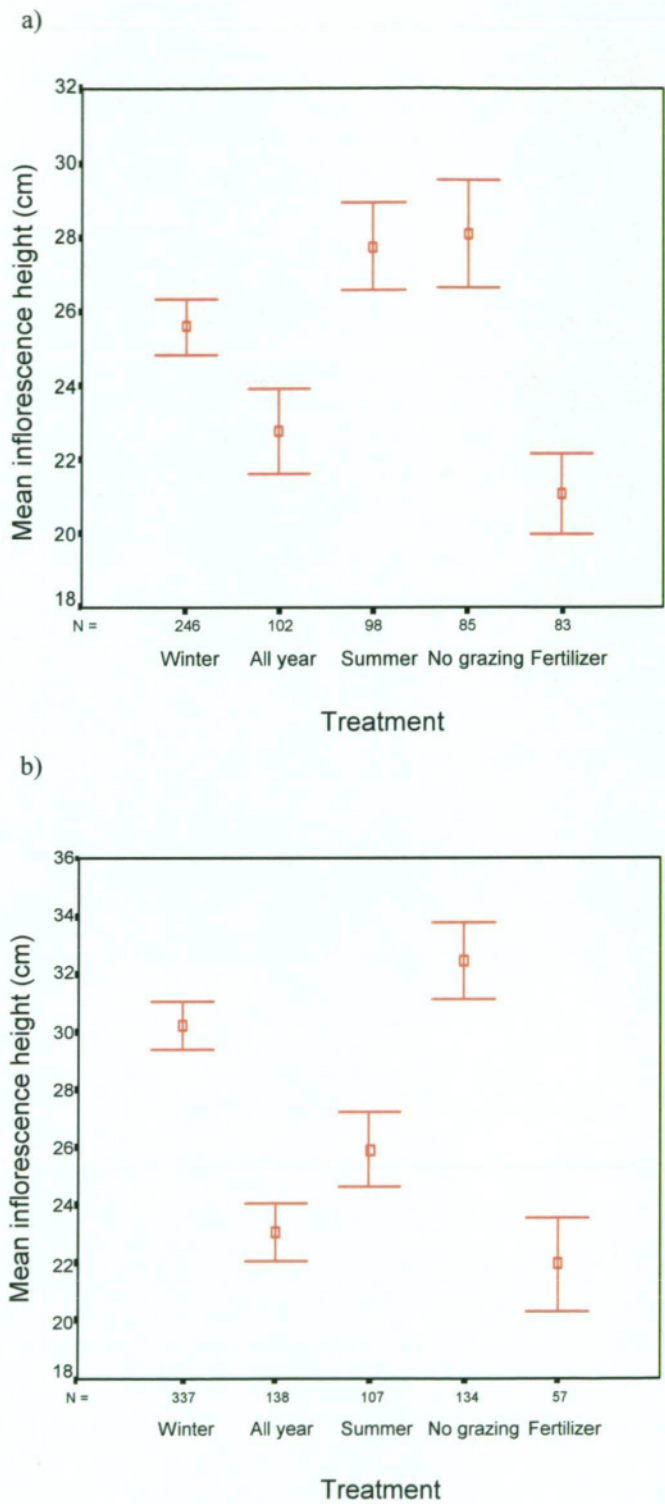
No-grazing > winter > summer > (all year and fertilizer)

In the previous year, results were generally similar, although mean inflorescence height was taller for summer than winter grazed plots and no significant difference was recorded between the summer and non-grazed treatments.

Several other populations observed in 2000 that were subject to long-term, all-year and heavy grazing were also observed to have short flower stems. The Lake River population, for example, had

noticeably short flowers stems with most being under approximately 15cm while plants outside the fence had more typical heights (>20cm).

While the fertilized treatment did not exhibit any significant differences to the all year grazed in any measure, the general appearance of the plots was one of heavy grazing. Grass in these plots was distinctively different to other treatments with a greener tinge and an apparent higher proportion of exotic species such as *Aira caryophylla*.



**Figure 4.4:** Mean inflorescence height ( $\pm 2se$ ) for *Brunonia* following five grazing treatments in a) 2000 and b) 2001.

#### 4.3.4 Analysis of populations 2000

The Principal Coordinates Analysis of populations displayed no obvious trends in terms of grazing influence on *Brunonia* density. In the analysis of all populations (Table 4.4), most factors (variables) had an equal bearing on variance in the 1<sup>st</sup> eigenvector, which accounted for more than 25% of variance. The groups were more distinguished in the second and third eigenvectors by obvious groupings of variables such as sheep versus cattle factors (2<sup>nd</sup> eigenvector) or *Brunonia* measures only (3<sup>rd</sup> eigenvector).

In the analysis of only those populations subjected to sheep grazing (sheep, Table 4.5), similar results were obtained. The 3<sup>rd</sup> eigenvector, accounting for almost 13% of variance, did however suggest that *Brunonia* density class might be positively correlated with sheep density. While this feature is less important than the influence of the combination of variables (1<sup>st</sup> eigenvector), it does suggest that a high sheep density is not necessarily detrimental to *Brunonia* density.

For the analysis of only those populations subjected to some cattle grazing, sheep season and intensity displayed negative correlation to *Brunonia* numbers and density (Table 4.6). As stated earlier, it is important to note that most of the properties that had cattle grazing also had sheep grazing. It seems that cattle grazing as such was not necessarily causing an impact but that the associated sheep grazing patterns on these properties had an increasingly negative effect on *Brunonia* because their grazing regime moved from lower stock numbers in winter to higher numbers all year.



**Table 4.4:** Principal Coordinates Analysis output for grazing and *Brunonia* parameters across all sites in 2000.

VARIANCE EXTRACTED, FIRST 3 AXES				
AXIS	Eigenvalue	% of Variance	Cum.% of Var.	Broken-stick Eigenvalue
1	4.1	25.6	25.6	3.4
2	3.2	20.2	45.8	2.4
3	3.1	19.0	64.8	1.9

## FIRST 3 EIGENVECTORS

Variable	Eigenvector		
	1	2	3
no. sheep	0.19	-0.38	-0.14
sheep den	0.23	-0.40	0.00
sheep sea	0.32	-0.20	-0.22
sheep int	0.30	-0.19	-0.17
no. catt	0.21	0.31	-0.24
catt dens	0.25	0.31	-0.19
catt seas	0.27	0.28	-0.24
catt int	0.30	0.30	-0.25
tot den	0.24	-0.40	-0.00
paddock(ha)	-0.11	-0.10	-0.31
pad/for	0.21	-0.22	0.01
grass	0.29	0.07	-0.13
ba area	-0.25	-0.11	-0.40
ba no.	-0.28	-0.11	-0.37
ba dencl	-0.22	-0.05	-0.38
ba den	-0.27	-0.07	-0.35

VARIABLES: no. sheep = no. of sheep grazed on property; sheep den = sheep density no. - sheep/paddock area; sheep sea = sheep season, 1=winter, 2=summer, all year; sheep int = sheep grazing intensity class, 1=low, 2=medium, 3=high; cattle measures as for sheep; tot den = total density, (sheep + cattle no.s)/paddock area; paddock = total paddock area (ha) including forest and pasture areas; pad/for = paddock area/forest area (ratio); grass = grass cover scale, 1=low, 2=mod., 3=mod-high, 4=high; ba area = area covered by *Brunonia* (ha); ba no. = estimated no. of *Brunonia*; ba den = *Brunonia* density class, 1=nil to few, 2=low-mod., 3=mod., 4=mod-high, 5=high to very high; ba den = ba density, no. estimated/ba area.

**Table 4.5:** Principal Coordinates Analysis for grazing and *Brunonia* parameters in only those sites with sheep grazing. (Refer to Table 4.4 for variable definitions).

VARIANCE EXTRACTED, FIRST 3 AXES				
AXIS	Eigenvalue	% of Variance	Cum.% of Var.	Broken- stick Eigenvalue
1	5.0	31.5	31.5	3.4
2	3.4	21.3	52.8	2.4
3	2.1	13.0	65.8	1.9

FIRST 3 EIGENVECTORS			
Variable	Eigenvector		
	1	2	3
no. sheep	0.01	0.30	0.31
sheep den	0.11	<b>0.40</b>	<b>0.38</b>
sheep sea	0.29	0.02	0.16
sheep int	0.25	0.06	-0.28
no. catt	0.21	-0.32	0.31
catt dens	0.23	-0.32	0.28
catt seas	0.22	-0.36	0.16
catt int	0.27	-0.34	0.10
tot den	0.11	<b>0.40</b>	0.39
paddock (ha)	-0.31	-0.11	-0.07
pad/for	0.13	0.22	0.09
grass	0.26	-0.10	0.08
ba area	-0.35	-0.12	0.11
ba no.	-0.34	-0.10	0.22
ba dencl	-0.28	-0.16	<b>0.35</b>
ba den	-0.33	-0.13	0.30

**Table 4.6:** Principal Coordinates Analysis for grazing and *Brunonia* parameters in only those sites with cattle grazing. (Refer to Table 4.4 for variable definitions).

VARIANCE EXTRACTED, FIRST 3 AXES				
AXIS	Eigenvalue	% of Variance	Cum.% of Var.	Broken- stick Eigenvalue
1	4.2	29.8	29.8	3.3
2	3.0	21.3	51.0	2.3
3	2.1	15.1	66.1	1.8

FIRST 3 EIGENVECTORS			
Variable	Eigenvector		
	1	2	3
no. sheep	0.20	-0.47	0.01
sheep sea	<b>0.34</b>	-0.07	0.32
sheep int	<b>0.37</b>	0.08	0.36
no. cattle	-0.21	-0.34	-0.29
catt seas	0.18	-0.05	0.20
catt int	0.25	-0.11	0.27
tot den	0.25	-0.41	-0.18
paddock (ha)	-0.11	-0.12	0.41
pad/for	0.18	-0.49	-0.13
grass	0.09	-0.06	0.35
ba area	-0.28	0.06	0.28
ba no.	<b>-0.40</b>	-0.11	0.30
ba dencl	-0.31	-0.32	0.16
ba den	<b>-0.36</b>	-0.30	0.20

A subjective look at the largest populations of *Brunonia* revealed some of its relationships with disturbances. Many of these populations have been subjected to occasional disturbances, including winter grazing. Table 4.7 summarizes the disturbance history of the nine largest and densest sub-populations (patch). Those sub-populations in the table that are recorded as open to stock all year, were confirmed with landowners as being effectively winter grazed as stock avoided forest areas in favour of adjacent pastures during spring/summer months.

**Table 4.7:** Disturbance regimes in the nine largest sub-populations of *Brunonia* in Tasmania. (not in order of size)

Population	Forest type*	Disturbance history
Glen Stuart (densest seen)	Grassy inland <i>E. amygdalina</i>	Strictly winter grazed at approx. 20 sheep/ha
Powranna (Nature Reserve patch)	Grassy inland <i>E. amygdalina</i>	Historically winter grazed at approx. 1.2 sheep/ha
Lefroy	Siliceous <i>E. obliqua</i>	Occasionally burnt by wildfire, logged within last 20 years.
Westwood (Viney patch)	Grassy inland <i>E. amygdalina</i>	Winter grazed at approx. 1 head cattle/ha
Carr Villa	Grassy inland <i>E. amygdalina</i>	Occasional fire
Carrick West (Walker patch)	Grassy inland <i>E. amygdalina</i>	Open to stock all year but effectively winter grazed at approx. 3.8 sheep/ha
Carrick East	Grassy inland <i>E. amygdalina</i>	Open to stock all year but effectively winter grazed at approx. 0.9 sheep/ha, regularly burnt (<5yr interval)
Deddington South	Grassy inland <i>E. amygdalina</i>	Infrequently grazed by sheep
Selbourne east	Grassy inland <i>E. amygdalina</i>	Open to stock all year but effectively winter grazed at approx. 4 sheep/ha

\* after Duncan and Brown (1985). NB. All grassy inland *E. amygdalina* patches were on Tertiary alluvial soils.

#### 4.4 Discussion

Winter grazing was associated with a significantly greater increase in the number of *Brunonia australis* rosettes compared with non-grazed and, probably, summer grazed treatments after only two years. The additional vegetative growth observed in all treatments was likely to be a result of excellent growing conditions in the spring of 2001. The proportion of germinants to total rosettes in 2001 was also significantly higher in the winter grazed plots compared to the low number observed in all other treatments. The restriction of grazing during the flowering and seeding period of *Brunonia* (spring-early summer) allowed a much higher reproductive output: ie. more successful flowering, seed production and dispersal. Similar observations have been made on other grassland dicotyledons (e.g. Duffey *et al.* 1974; Dickinson and Kirkpatrick 1986). In contrast, reduction in competing species by grazing over the winter months permitted a higher successful germination percentage and seedling survival. Flowering and seeding also remained uninterrupted in the non-grazed plots but the lack of inter-tussock spaces, amongst the dense grass growth, restricted

successful seedling establishment, consistent with observations by Stuwe and Parsons (1977) on a broader range of species in the grasslands of Victoria.

The proportion of flowers to rosettes (PFR) in winter grazed plots was also higher than for all other treatments except the non-grazed treatment. This is not surprising as the rosettes that were capable of resprouting in the ungrazed plots were generally well established plants capable of sending up one or more flowering stems, especially in the excellent growing season of 2001. Increase in inflorescence height in the ungrazed and winter grazed treatments may have resulted from a combination of improved plant health and leaf area, lack of browsing on the tallest stems compared to other treatments, or as a response to increased height competition and shading from surrounding plants.

The results of this study support the observation that a cessation of grazing in grassy ecosystems may have a negative impact on herbaceous species such as *Brunonia australis* (Gibson and Kirkpatrick 1989; Fensham and Kirkpatrick 1989; Duncan 1991; Belsky 1992). Many of the densest populations of *Brunonia*, including some where it was the dominant herb, were found on properties that were subject to a winter grazing regime (Table 4.7). As the majority of *Brunonia* individuals have lost their leaves and shed their seed by early autumn, even heavy ‘winter’ grazing from this period through to about September when the leaves are resprouting, would not seriously affect the population. A severe reduction in competition on productive sites is likely to be advantageous to the species due to its relatively slow growth rates after germinating or resprouting in spring (Duffey *et al.* 1974; Hitchmough *et al.* 1989). Duffey *et al.* (1974) recommend heavy winter grazing in temperate grasslands on moderate fertility sites, to allow consumption of dead and dying plant material of low nutritional value that would otherwise shade out plants with low stature. In the Tasmanian Midlands, presumably for similar reasons, Kirkpatrick (1991) recommends grazing over no grazing in grassy vegetation. Tremont (1994) reported a much higher proportion of forb species with rosettes in a grazed treatment compared to an ungrazed treatment after 16 years of grazing or exclusion in adjacent areas of temperate grassland on the New England tablelands. McIntyre *et al.* (1995) found in the same ecosystems that species with similar life forms to *Brunonia* (flat-rosette hemicryptophytes) (*sensu* Raunkiaer) responded positively, compared to other life forms, to a

moderate level of grazing but were negatively affected by low and high levels of grazing. The season of grazing was not discussed but observations were made during the “growing season”. They propose that the low form of flat-rosette-hemicryptophytes (rosette plants with persistent buds at about ground level), often allows avoidance of grazing which otherwise targets taller plants. A similar response is probably happening at the Carrick study site during spring/summer, where a moderate level of grazing during the leaf period of *Brunonia* is not affecting its persistence. The suggestion by Kirkpatrick and Gilfedder (1999b), that *Brunonia* will be eliminated if grazing is too heavy, is an over simplification. The evidence suggests that season of grazing is inextricably linked to grazing intensity when it comes to the success of *Brunonia* at a site.

Grazing also reduces structural complexity (Dickinson and Kirkpatrick 1986, Wilson 1990) and in the case of *Brunonia*, which thrives in sunny situations, the restriction of shrub growth is potentially beneficial in some areas. The obverse of this can be seen in some of the Launceston Parks, such as Kate Reed Reserve and Blue Gum Park, where a long term lack of disturbance has allowed dense *Allocasuarina*, *Acacia*, *Banksia* and eucalypt regrowth to occur. In these patches, *Brunonia* is restricted to the edges of walking tracks, slashed areas and other small openings. Historically, heavy populations of native grazing animals and aboriginal fire regimes probably maintained a suitably open understorey for many herb species like *Brunonia* (Gilfedder *et al.* 2003). More recently, limited burning and intensive “game” control by landowners, typical in the dry forest remnants containing the species, has increased the likelihood of denser understorey development.

Populations occurring in areas of lower site quality where grasses and other species are not likely to take over (Kirkpatrick *et al.* 1988), may not require any grazing. A dense population at Lefroy on siliceous soil has been occasionally burnt but never subject to grazing. Others at Epping Forest and Deddington on lateritic soils have persisted with very low levels of disturbance. It is unclear what influence native and feral herbivores have on the species and this presumably varies from area to area. Bolton and Latz (1978) report grazing of *Brunonia* by a macropod in the Tanami desert and chewed leaves and flower heads have been commonly observed in Tasmanian populations in areas

not grazed by domestic livestock. Rabbits, brush-tailed possums and various macropods are suspected browsers of *Brunonia* in Tasmania.

Without due caution, the potential impacts of summer grazing on *Brunonia* may be misinterpreted where dense populations are found in forest open to grazing all year. Where the patch of forest adjoins an area of pasture, stock grazing is likely to concentrate on the pasture areas in spring and summer when grass growth is good and then move to the forest areas in winter when supplementation is required. In essence, a winter dominated grazing regime is in operation in the forested area. The prevalence of *Brunonia* at the study site suggests that the area was subject to such a grazing pattern. The impacts of grazing on *Brunonia* (and other species) in this study, particularly in the summer only and all year grazed plots, may have been limited because the grazing regime was no different to that which already allowed persistence of the species at the site. Stock were observed in the study area at all times of the year, but grazing of plots opened in winter was likely to be heavier than those opened in summer. Under these circumstances a longer period than two years would be required to observe any strong differences between summer and winter grazing treatments and that of all year grazing. Williams (1969), however, suggested that even after 16 years of grazing by sheep on a riverine grassland, no annual species were eliminated because the grazing regime over the period of the study was the same as that which brought about the development of the grassland. Similarly, a change of summer grazing pattern or intensity is probably required before any strong trends are observed for *Brunonia* at the Carrick site. Fertilizer treatments may also need to be undertaken for longer periods before any potential significant impacts are observed.

The grazing analysis of all populations suggested that grazing factors alone are not the main influence on *Brunonia* densities across its range. Many other factors such as fire history, logging history, past clearing, past grazing regimes, gravel extraction, soil types and other environmental parameters are also likely to have had an influence but relationships between these factors are poorly understood (Dickinson and Kirkpatrick 1986). The contention of the study at the Carrick site that winter grazing is preferable to all year or summer grazing was however supported by the analysis of 12 populations subject to cattle grazing. Most of these populations also had sheep grazing. Summer

and all year grazing coupled with increasing sheep grazing intensity class was negatively correlated with *Brunonia* numbers and density. It is therefore surmised that in this selection of populations, sheep grazing regime was one of the major influences on *Brunonia* density.

The ability of *Brunonia* to recover from constant grazing pressure is unclear. The species has an ability to regenerate from rootstock but the longevity of the plant without resprouting is not known. One site of less than 1 hectare in a back yard at Devon Hills was observed to contain *Brunonia* after heavy grazing by Shetland ponies and horses was ceased for the first time in many years. In a previous year a search for *Brunonia* did not reveal any plants over this small area but their multi-rosette form confirmed these individuals were older than one year. In a study on logging impacts on *Brunonia* (Hawkins unpubl.) the previous seasons seed heads were used to locate plants in thick grass, and succulent roots were found on apparently dead individuals that had no leaves during the height of their normal leaf period (late spring- early summer). It appears that the species will persist for a time by its rootstock, possibly years, and will then resprout fully in a year when conditions are more favourable. This may also help explain why the species is capable of surviving in some of Australia's harshest deserts and is often noted in a recently disturbed area.

The diverse range of results in studies on the floristic impacts of grazing suggest that care must be taken when interpreting results, particularly when based on a single site (Gibson and Kirkpatrick 1989). Ball (1974) also recommends at least three observations over a period of time before trends in the status of plants can be reliably reported. Other factors may also influence grazing impacts on *Brunonia* between different sites including the successional stage of the vegetation (Gibson *et al.* 1987), the range and abundance of plant species present and their relative palatability to the herbivore(s) present (Pacala and Crawley 1992) and site quality (Gibson and Kirkpatrick 1989). Type of herbivore was not closely examined in this study but there were no apparent trends between sheep and cattle in populations examined in 2000. Both high and low densities of *Brunonia* were observed in sites subject to cattle grazing.



## 4.5 Conclusion

Winter grazing by sheep (Apr.-Sept. inclusive) in a grassy forest of moderate site quality, was found to benefit *Brunonia australis* after only two years, compared to non-grazed, summer grazed (Oct.-Mar. inclusive), all year grazed, and fertilized / all year grazed treatments. Even heavy grazing during the winter dormant period of this species is unlikely to decrease numbers and may indeed be beneficial through the reduction in competition. Several of the largest and densest populations of *Brunonia* are found in areas that have had sustained winter grazing regimes. Cessation of grazing on sites of moderate or better quality may permit either dense understorey (e.g. grasses) or shrub regrowth that will eventually out-compete or shade out *Brunonia* causing population contraction.

A number of new reserves and management agreements have been placed over populations that have been historically subject to at least winter grazing. Care is required that the open nature of these sites is not compromised through restriction of grazing and preferred habitat conditions for *Brunonia* diminished. Future studies are required to determine optimum grazing regimes for the species in relation to the needs of other species on a site. Grazing every winter may benefit *Brunonia* but a heavy winter grazing every second or third season may be as effective but less detrimental to other species.

## 4.6 Acknowledgements

Many thanks to Gil and Dawn Walker for making their property available for the study, Mike Peterson for assistance with data analysis, Rachelle Hawkins for field booking work and Gunns Ltd for valuable support of the project.

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## 5. Impacts of logging and silvicultural practices on *Brunonia australis*, a case study.

Craig Hawkins, Dr Rob Wiltshire, Dr Greg Jordan

**Abstract.** The effects of 4 logging and silvicultural treatments on the threatened herb *Brunonia australis* were investigated in a grassy *Eucalyptus amygdalina* forest near Bracknell, northern Tasmania. 3 replicates of 20x20m quadrats were subjected to either (selective) logging only, logging and mechanical scarification, logging and top-disposal burning or no treatment. Summer counts of rosettes and flowers were made in each quadrat prior to treatment, 1 year after treatment and 3 years after treatment. Rosette numbers declined after 1 year in the scarified treatment compared to all other treatments. Rosette numbers also declined significantly in burnt 4x4m plots when compared to unburnt plots randomly chosen from within the burn treatment quadrats. Scarification had a direct impact on plants but the dense recovery of other understorey plants in burnt areas caused increased competition for *Brunonia*, which subsequently declined. Flowering increased following all logging treatments with the proportion of flowering rosettes significantly greater in logged quadrats, than in unlogged quadrats, both 1 year and 3 years after treatment. Burnt quadrats flowered well but plants affected directly by fire flowered poorly in the first year after treatment due to a shortage of recovery time between the October burn and the normal flowering period in late November-December. Autumn burning may avoid this problem. This study has shown that widespread heavy scarification or broad-scale burning is likely to be detrimental to the herbaceous understorey following logging in dry grassy forests of moderate productivity. Forest managers need to choose silvicultural systems in these forests that provide an adequate eucalypt seedbed through patchy burns or light ground disturbance as well as ensuring effective early regeneration success through use of supplementary seed sowing and game control. Management of the post-logging disturbance regime is as important as selection of the silvicultural system for maintaining understorey species diversity. Periodic disturbances will need to be re-introduced as soon as possible after logging and eucalypt regeneration to help limit the proliferation of aggressive understorey species which eventually out-compete understorey herbs such as *Brunonia*.

## 5.1 Introduction

The need for ongoing scientific research into the most appropriate techniques of logging to maintain the range of ecological values in forests has been acknowledged by the forestry profession (Drielsma 1992; Squire 1993; Abbott and Christensen 1994; Abbott and Burrows 1999; Forest Practices Board 2000). Appropriate logging techniques are of particular importance in remnant forest types and areas containing threatened species where poor management options can have a substantial impact on both local and regional conservation goals. Dry inland eucalypt forests in Tasmania are amongst the most heavily impacted and poorly reserved communities in the state. There has been more than 80% reduction in forest cover in the midlands region since European settlement (Fensham and Kirkpatrick 1989) and current reservation of remaining communities is generally less than 10% (<4% for Inland *Eucalyptus amygdalina* forest) (Tasmanian Government 1996a). These communities also contain a high proportion of threatened plant species (Kirkpatrick *et al.* 1988, Fensham and Kirkpatrick 1989) but the current understanding of logging impacts on understorey plants in these forest types, is largely limited to anecdotal evidence. Management has been based on broad ecological principles with the focus on the maintenance of overstorey species (e.g. Orr 1991). A similar situation has been reported for some Victorian native forest types (Bennett and Adams 2004).

However, exclusion of disturbance may not ensure maintenance of species diversity. A range of threatened plant species in Tasmanian dry forests respond positively to certain types of disturbance including fire, grazing, or mechanical soil disturbance (Kirkpatrick and Gilfedder 1999). However, responses may vary with the type of disturbance, so it is inappropriate to base management techniques of threatened species solely on broad ecological principles. More targeted research is required. The threatened herb *Brunonia australis*, listed as ‘vulnerable’ on the Tasmanian *Threatened Species Protection Act (1995)*, may be a useful model species to examine the responses to disturbance for a range of understorey herbs and forbs in dry, open eucalypt forests. The presumption has been that *Brunonia* persists in disturbed areas (Tasmanian Government 1996b) and permits have been issued under the *Threatened Species Protection Act (1995)* allowing logging in areas of occurrence, but no studies have been undertaken to examine this assumption. This chapter

reports the response of *Brunonia* to three typical logging and silvicultural treatments in an Inland *E. amygdalina* forest near Bracknell, northern Tasmania.

## 5.2 Method

### 5.2.1 Study site

The study site was a 15ha privately owned, 'inland *Eucalyptus amygdalina*' (black peppermint) forest on Tertiary alluvial soil (GR 932907 Cluan 1:25,000 mapsheet). Elevation of the site is approximately 210m a.s.l., landform is uniformly flat and annual average rainfall is 820mm with a winter bias. Weather details were recorded at "Sand Park", Bracknell, 3km southeast of the study site. The forest was dominated by mature and over-mature *E. amygdalina* with occasional *E. viminalis* (white gum). Past disturbances at the site have been occasional firewood cutting and light grazing by sheep and cattle. No fire was known to have occurred in the area for more than twenty years. The understorey was generally open and dominated by herbs and grasses with frequent, denser patches of bracken (*Pteridium esculentum*). Weeds were limited to a few patches of gorse (*Ulex europaeus*), some thistles (e.g. *Cirsium vulgare*), grasses (e.g. *Holcus lanatus*) and other species (e.g. *Centaureum* sp.).

### 5.2.2 Pre-survey

The site was surveyed for *Brunonia* using a series of parallel transect lines 50 metres apart, the first line randomly located. The number of *Brunonia* rosettes observed along 10m sections and within 2m either side of the survey line was recorded. The main patches of *Brunonia* were identified. Basal area was measured using a factor 4 basal area wedge every 20m along transect lines.

### 5.2.3 20x20quadrats

Three one-hectare squares were subjectively located across the main *Brunonia* distribution. An additional 1ha control square was located subjectively in a contiguous area of the distribution but which would not interfere with logging (Fig. 5.1). Each of the three 1ha areas was randomly assigned a harvesting/silvicultural treatment:

selective logging (logged only)

selective logging and post harvest scarification (logged-scarified)

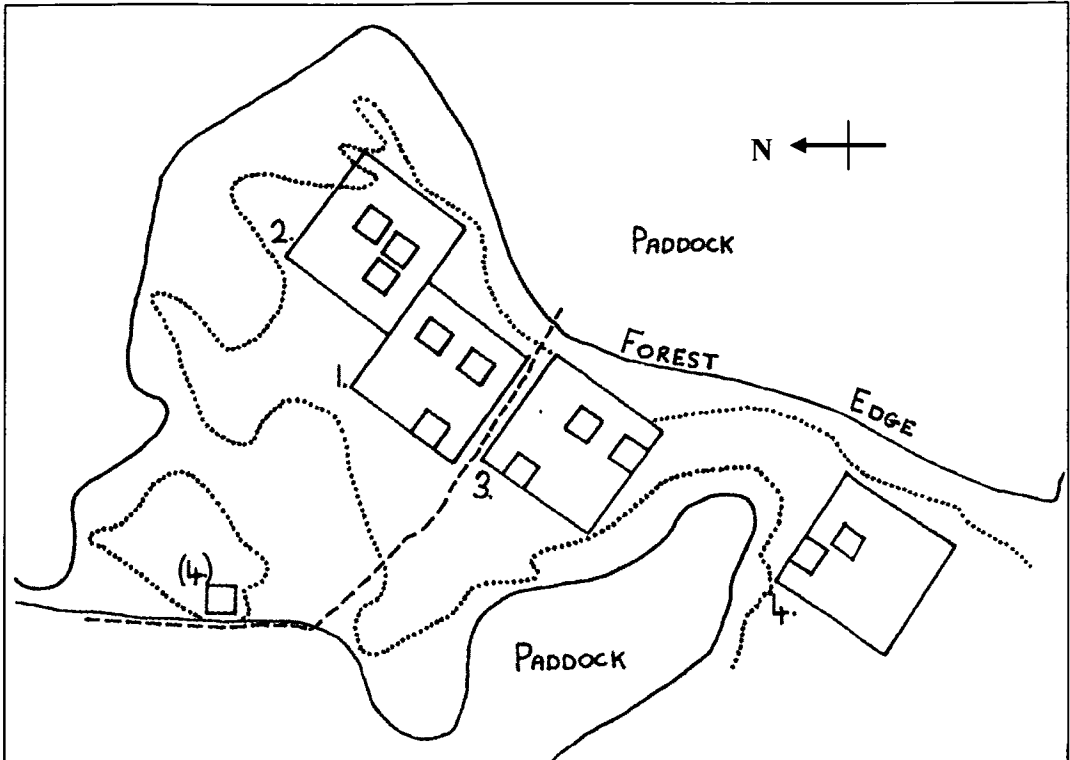
selective logging and top – disposal burning (logged-burnt)

One hectare was determined to be the most practical area for effective and safe application of each treatment, particularly burning, and a suitable area to monitor eucalypt regeneration (Pennington and Ellis 1997). The preferred random location of replicates could not be applied due to the restricted area and the need to keep the project within achievable limits. Because the site was physically, geologically and floristically uniform, and the 1ha plots were within close proximity, it was considered feasible to randomly locate three 20x20m-quadrat replicates within each 1ha, from a grid of 25 squares (Fig. 5.1). This design permitted operations to be conducted with minimal intervention over a broad scale area, allowing a more accurate reflection of typical practices and levels of disturbance in these forest types. Smaller plots would have meant artificially close control over disturbance factors such as intensity of skidder activity, scarification and total burn coverage whereas 1ha plots, and 20x20m quadrats within them, were of sufficient size to incorporate the normal range of disturbance levels associated with these practices. Interpretation of results has been discussed with consideration of the pseudoreplication in the design.

The northwest corner of each quadrat was permanently identified in the field with a steel star picket and the perimeter located with compass and measuring tape. A 20x20m quadrat was considered a suitable scale to monitor a patch of *Brunonia* logged using a non-interventionist approach for the treatments. That is, the logging crew was directed to harvest the area as they normally would and were given few details about the quadrats.

Quadrats were further divided into twenty-five 4x4m plots using dropper posts at four metre intervals on the perimeter and string lines between them.





**Figure 5.1:** Layout of the Bracknell study site including 1ha treatments squares (1=logging only, 2=log/scarify, 3= log/burn, 4= unlogged control) and smaller 20x20m quadrats. The dotted line indicates the approximate extent of the *Brunonia* population.

#### 5.2.4 Data collection

Data were collected during the flowering period of *Brunonia* (late November to late January):

1. Prior to logging (summer 1998/99)
2. In the first season after logging and silvicultural treatment (summer 1999/00)
3. Three years after treatment (summer 2001/2002)

The following information was collected in 20x20m quadrats, each divided into 25 4x4m subplots:

No. of *Brunonia* rosettes

No. of *Brunonia* flowering heads

Using two 4m measuring poles to further subdivide plots into four 2x2m subplots, the distribution of rosettes was mapped.

Basal area from the centre of each 20x20m quadrat was also recorded using a factor 4 basal area wedge.

Physical measures such as slope, aspect and elevation were not recorded, as the site was uniformly flat with no dominant aspect.

Following treatment, disturbance in each quadrat was mapped including burnt area, scarified and snig track disturbed areas and significant slash piles. A disturbance type was assigned to each 4x4m plot if more than 50% of the plot was affected.

#### 5.2.5 Logging and regeneration treatments

Logging commenced in April 1999 and was completed within 4 weeks using conventional ground based techniques, with manual falling and snigging with a rubber tyred skidder (Fig. 5.2). All pegs and string lines were removed prior to logging except the northwest corner peg of each quadrat. The logging crew was directed to retain a basal area of approximately 8-12m<sup>2</sup>/ha across the coupe and to avoid construction of any major snig tracks from other areas of the coupe in the vicinity of the quadrats. All normal feeder snig tracks were permitted.



**Figure 5.2:** Conventional ground based logging with a rubber tyred skidder at the Bracknell study site.

### 5.2.5.1 Burning measurements

#### *Fuel load and measurement of fire intensity*

After harvesting, each 4x4m plot in the logged-burnt treatment was divided into four 2x2m subplots by two 4m measuring rods. Relative pre-burn and post-burn fuel volumes for dead and live matter to 25mm diameter were recorded in each subplot before and after the burn, using a variation of the approximations for 6mm fuels in Anon. (1984). Only fuels to knee height were considered important as a potential influence on *Brunonia*. The initial fuel volume and the post-burning change in volume were used as a surrogate measure of fire intensity. The percentage area burnt in each subplot was also estimated to the nearest 10%. Fire intensity was only assigned to subplots with burn coverages of more than 50%.

Subplots were categorized as either:

- not burnt – <50% of subplot area burnt
- burnt at high intensity – an initial fuel volume >10t/ha reduced by more than 75% in the burn
- burnt at low intensity – remaining burnt subplots with >50% coverage

The overall intensity assigned to the 4x4m plots was determined as the intensity rating with the overall greatest coverage in the component subplots. In the following example (Table 5.1) the overall plot was considered burnt at high intensity (H) despite one subplot being considered low intensity (L) and the other unburnt. Generally most plots were either clearly burnt at high intensity or not.

**Table 5.1:** Sample determination of a 4x4m plot burn intensity using 2x2m subplots.

Subplot no.	Estimated pre-burn fuel load (t/ha)	Estimated post-burn fuel load (t/ha)	% Fuel load reduction	Subplot burn coverage	Intensity Rating (1=H, 2=L, 0=unburnt)
1	2.8	0.8	71	50	2
2	21.0	0	100	100	1
3	13.2	0	100	90	1
4	5.2	4.0	23	30	0

#### *Fuel moisture*

Eleven samples of head (slash) fuels, four of ground (litter) fuels, and five of live fuels (grasses etc) were collected at representative sites near quadrats in the burn area just prior to burning. Each sample was placed into a sealed plastic bag and weighed prior to oven drying. Two days after collection, bags were opened and placed into a Qualtex Solidstat drying oven for 14 days. Due to a faulty oven thermometer the temperature was set at 45 C for the first week but was raised to 65 C. for the final week.

Percentage fuel moisture content for each sample was calculated using:  $(A-B) / (B-C) \times 100$

where:

A= Bag and fuel pre-drying

B= Bag and fuel post-drying

C=Bag

Average fuel moisture was calculated for each fuel type.

#### *Day of Burn*

Burning was conducted on 20 October 1999 commencing at 3.00pm. Basic weather measurements included temperature, relative humidity, wind at 1.7 m and cloud cover. Flame height was recorded in slash heaps and for ground fire, to the nearest half metre or to the nearest 10 cm if less than half a metre high.

#### *5.2.5.2 Scarification*

Scarification was conducted on 31 May 1999 using a front mounted root rake on an International TD15 bulldozer (Fig. 5.3). Scarification was aimed at removing all vegetation and debris back to bare earth except within about 2 metres of retained trees. The majority of each quadrat designated for this treatment was scarified.





**Figure 5.3:** International TD15 used for scarification.

## 5.2.6 Analysis

### 5.2.6.1 Rosettes

#### *Proportional change in rosette numbers*

The proportional change in rosette numbers was calculated for each quadrat for:

Pre-logging (0yr) to 1<sup>st</sup> summer after treatment (1yr)

Pre-logging (0yr) to 3<sup>rd</sup> summer after treatment (3yr)

1<sup>st</sup> summer to 3<sup>rd</sup> summer

Proportional change was defined as:                      latest count / earlier count

Proportions were log<sub>10</sub> transformed and compared between treatments using a one-way analysis of variance, using JMP4 (SAS Institute Inc. Cary, North Carolina)

*Proportional change in rosettes in response to fire and the presence of slash*

As the coverage of slash in the logged-only treatment was sporadic, the proportional change in rosette numbers was compared at the 4x4m plot level. Plots designated as containing significant slash coverage (>50% cover) were compared against plots from within the logged only treatment that did not contain slash. The non-slash plots were selected randomly such that there were the same number of plots as the slash covered plots, for each year.

The affects of fire on rosette numbers at the plot level was assessed in a similar way. The location of heads and their subsequent burning was considered to have occurred randomly across the quadrats in the logged-burnt treatment. Due to patchy coverage of the top-disposal burn, unburnt 4x4m plots were selected randomly, from within the logged-burnt treatment quadrats only, to compare against burnt plots.

A one-way analysis of variance was used to establish any significant differences and included a test for quadrat interaction effects using JMP4.

*Proportional change in frequency of occupied 2x2m subplots*

*Comparison between treatments*

Frequency was defined as the number of subplots per quadrat (100 per quadrat) occupied with at least one *Brunonia* rosette. It enabled a further comparison between treatments that considered impacts on the spread of *Brunonia* across the whole quadrat. This minimized the chance of misinterpreting treatment effects on total rosette numbers, as calculated above, due to significant impacts on only one or two high numbered patches of *Brunonia* in any quadrat (for example a hot top disposal burn over the only large patch of *Brunonia* in a quadrat).

Proportional change in frequency was calculated as described for the rosette numbers above and a one-way analysis of variance conducted using JMP4.

*Within-treatment comparison of rosette count vs frequency count*

Each treatment was separately analyzed using one-way analysis of variance (JMP4), to test whether the proportional change in the frequency of 2x2m subplots occupied per quadrat was different from the proportional change in total number of rosettes per quadrat.

The analysis was only based on the changes from 0yr to 3yr. The ratios (3yr over 0yr) were  $\log_{10}$  transformed for calculation.

**5.2.7 Proportion of rosettes flowering (PFR)**

Due to the change in rosette numbers following treatments, the effect on flowering was examined using the proportion of rosettes flowering in each quadrat for each year (0yr; 1yr; 3yr). A comparison between years was not considered relevant due to the unknown effect of normal fluctuations.

Proportions of flowers/rosettes for each quadrat were  $\log_{10}$  transformed and compared between treatments using a one-way analysis of variance using JMP4.

As for rosette counts, the PFR for burnt plots was compared against randomly chosen unburnt plots from within the burn treatment quadrats for 0-1yr, 0-3yrs and 1-3yrs. Each period was treated separately with no comparisons made between years.

**5.2.8 Weather records**

Weather records were obtained from the property "Sand Park", approximately 3 kilometres to the east of the study site. Daily rainfall to 6pm was recorded in a 150mm Nylex rain gauge to the nearest millimeter (Appendix 4B). Long-term average rainfall was obtained from records kept at the Bracknell Post office from 1963 also approximately 3km south east of the study site.

Daily maximum and minimum temperatures were recorded at “Sand Park” from October 1997 at 6pm on a standard maximum/minimum thermometer kept in the shade (Appendix 4B). No long-term averages for the area were available.

5.3 Results

5.3.1 Coverage of treatments

Disturbance coverage and trends of *Brunonia* distribution over the 3 measurement years are mapped in appendix 4A. Mapped disturbance coverage for each quadrat included tree removal, slash coverage, scarification, and burnt area.

5.3.1.1 Basal area retention

The pre and post-treatment basal areas of eucalypts for each quadrat is presented in table 5.2.

Retained basal areas after logging were in the desired range for all quadrats.

Table 5.2: Eucalypt basal area (m<sup>2</sup>/ha) for all quadrats used in the trial. (A dangerous tree was removed from quadrat 31 following logging reducing the basal area from 8m<sup>2</sup>/ha).

Quadrat	Logged-only			Logged-Scarified			Logged-Burnt			Control		
	11	12	13	21	22	23	31	32	33	41	42	43
Pre-logging	36	28	16	32	20	32	32	36	20	56	32	44
Post-logging	12	8	12	8	8	8	4	12	8	56	32	44

5.3.1.2 Burning

Conditions on day of burn

Table 5.3 summarizes fuel moistures for fuels collected at the time of burning on 20 October 1999.

High live (grass) fuel moistures reflected the lack of curing that had occurred since winter allowing an effective burn in slash without risking a running ground fire.



**Table 5.3:** Fuel moisture for 3 fuel types collected at the time of burning.

Fuel type	Mean	St Dev	n
Head fuels	18.4%	3.7	11
Litter fuels	14.8%	0.8	4
Live fuel	121.8%	25.0	5

Weather conditions at the time of burning are given in table 5.4 and again reflect acceptable top-disposal burning conditions.

**Table 5.4:** Weather conditions and flame heights at the time of burning (1500-1700hrs).

Temperature:	17.5°C (1500hrs) - 16°C (1700hrs)
RH%:	72-81%
Cloud cover:	40-50% (increasing into evening)
Flame in heads:	3m high, 3m depth
Flame on ground:	0.3m high, 0.1m depth

Most fuels to 25mm were consumed in areas containing tree heads and other slash as indicated by flame heights in table 5.4, but burning was discontinuous on the ground due to bare earth resulting from logging and the moist live fuels. Under the definitions applied, 10 plots across the three replicates were considered burnt at high intensity and 15 plots at low intensity.

#### 5.3.1.3 Scarification

Scarification scalped most understorey vegetation back and exposed bare earth to a depth of approximately 25mm-50mm.

#### 5.3.2 General observations on the response of *Brunonia* to logging

Moderate mechanical soil disturbance by the skidder appeared to benefit *Brunonia* in the first year after logging in areas not burnt or scarified, with numerous robust plants and profuse flowering obvious along snig tracks. Table 5.5 shows the overall change in rosette numbers for each quadrat. Overall numbers from pre-logging (0yr) to 3yr increased in logged only quadrats, the control quadrats and marginally in one burnt quadrat but decreased markedly in the scarified and remaining burnt quadrats.

**Table 5.5:** Total number of *Brunonia* rosettes by treatment, before logging, 1 summer after logging/treatment and 3 summers after logging/treatment.

Treatment -	Logged-only			Logged-Scarified			Logged-Burnt			Control		
Quadrat -	11	12	13	21	22	23	31	32	33	41	42	43
Pre-logging 0yr (1998/99)	1165	1098	307	797	1655	538	583	289	332	304	255	851
Post-logging 1yr (1999/00)	1365	1149	211	117	590	202	590	269	218	407	317	1044
Post -logging 3yr (2001/2002)	1183	1349	443	244	555	310	443	299	130	582	427	1686

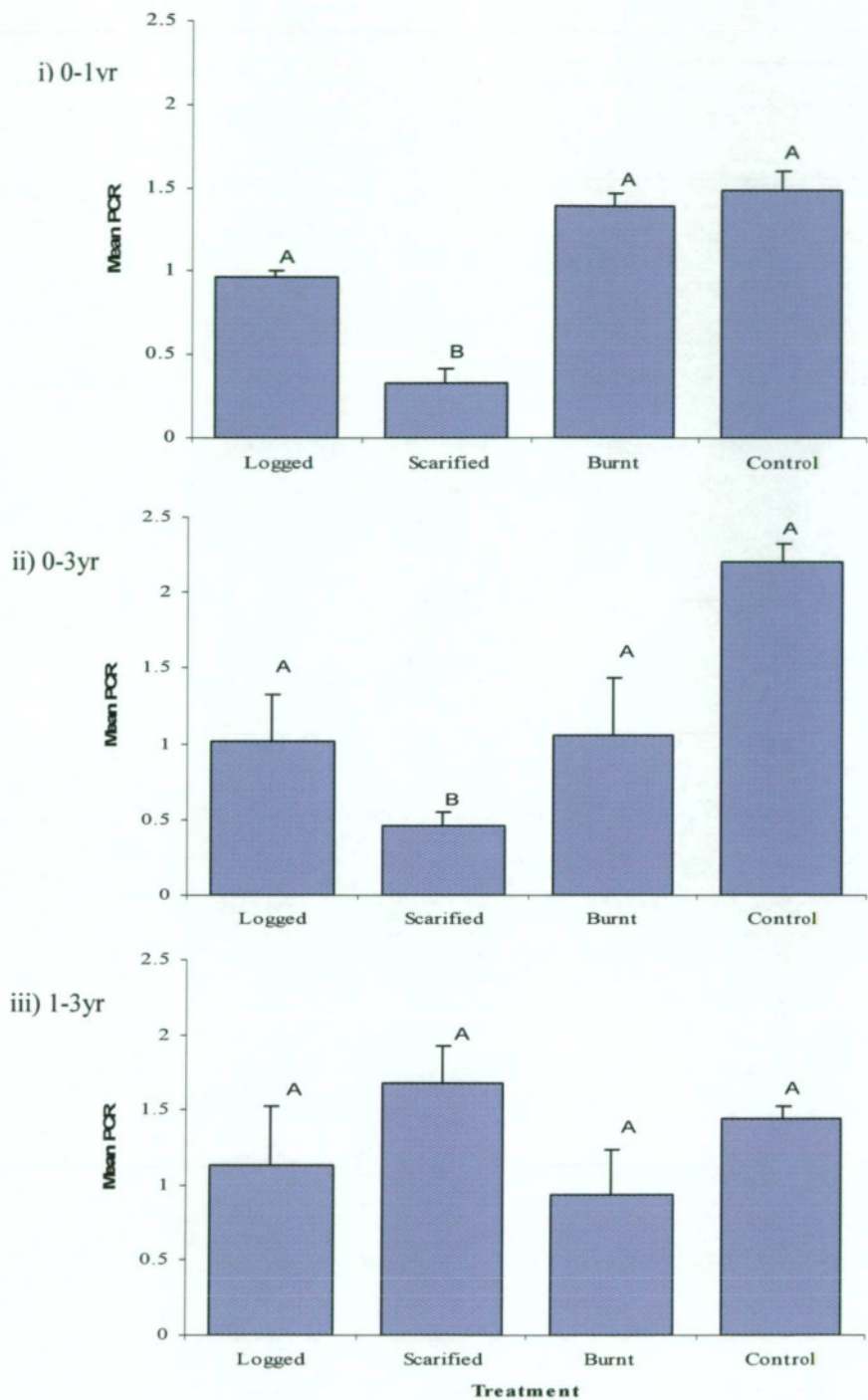
### 5.3.3 Effects on rosettes

#### 5.3.3.1 Proportional change in rosette numbers

Scarified quadrats displayed a significant change in rosette numbers ( $P < 0.05$ ) from 0yr to 1yr and 0yr to 3yr compared to the other treatments and the control (Fig. 5.4). There was no significant difference from 1yr to 3yr reflecting the fact that the decline was likely to be caused by the scarification itself and that there was neither subsequent continued decline nor a dramatic recovery. There were no other significant differences detected in the treatments.

#### 5.3.3.2 Proportional change in rosettes in 4x4m plots containing slash

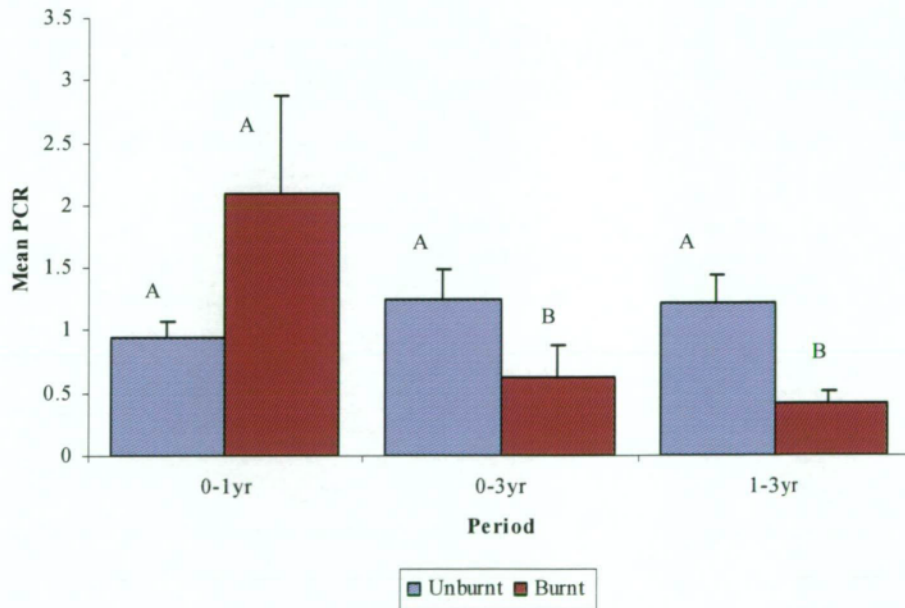
Despite the otherwise logical conclusion that coverage of dense slash would decrease plant abundance, there was no significant difference between slash covered versus non-slash covered plots. Mapping showed that there were enough surviving rosettes around the edges of slash piles to reduce the apparent impact in those plots.



**Figure 5.4:** Mean proportional change in rosette numbers (PCR) for 3 logging and silvicultural treatments (n=3) and an unlogged control from i) pre-logging to 1yr; ii) pre-logging to 3yr and; iii) 1yr to 3yr (B= significantly different at  $P<0.05$ ). Different alphabet letters indicate significant differences between treatments.

### 5.3.3.3 Proportional change in rosettes in burnt 4x4m plots

There was no significant proportional change in rosette numbers ( $p < 0.05$ ) in burnt plots compared to non-burnt plots (within the burnt treatment area) from pre-logging to 1yr. However, there was a significant change overall from pre-logging to 3yr ( $F_{1,37}=4.67$ ) and from 1yr to 3yr ( $F_{1,37}=5.81$ ) (Fig. 5.5). *Brunonia* were amongst the first plants resprouting in even the hottest burnt areas (Fig. 5.6). The pattern of resprouting typically resembled the mapped locations of plants prior to treatment indicating that recovery was from vegetative means rather than from seed. The subsequent decline in rosettes from 1yr to 3yr appeared to be a result of dense unchecked recovery of bracken (*Pteridium esculentum*), wattle (*Acacia dealbata*) and several weed species including fog grass (*Holcus lanatus*) and thistle (*Cirsium vulgare*). Recovery of these species, particularly wattle and bracken, was noticeably thicker in the patches where heads had been burnt. The decline from 1yr to 3yr was substantial enough to make the pre-logging to 3yr decline significant.



**Figure 5.5:** Mean proportional change in rosette numbers (PCR) for burnt and unburnt plots from pre-logging to 1year after logging (0-1), pre-logging to 3years after logging (0-3yr) and 1year after logging to 3years after logging (1-3yr) (B=significant at  $p=0.05$ , compared within each period only). Different alphabet letters indicate significant differences between treatments.





**Figure 5.6:** *Brunonia* (2 plants in centre of photo) recovering in a heavily burnt site 2 months after burning.

#### 5.3.3.4 Proportional change in frequency of occupied 2x2m subplots

##### *Comparison between treatments*

The frequency of subplots occupied by *Brunonia* declined in all treated quadrats except one burnt quadrat, where there was no change, but increased in all 3 control quadrats (Table 5.6). However, the only significant difference ( $p < 0.05$ ,  $F = 16.77$ ) detected for the period pre-logging to 1yr was for the scarified treatment compared to all other treatments. The result was similar for pre-logging to 3yr except that in this period there was no significant difference between the scarified and logged only treatments.

The dramatic decline in occupied subplots in the scarified treatment supported the observations of the decline of overall rosette numbers in that treatment. It also indicated that the decline was spread across the scarified quadrats and not just a few subplots that contained large numbers prior to treatment.

**Table 5.6:** Frequency of 2x2m subplots (of 100 per quadrat) occupied by 1 or more *Brunonia* rosettes.

Quadrat	Logged only			Scarified			Burnt			Unlogged		
	11	12	13	21	22	23	31	32	33	41	42	43
Pre-logging (1998/99)	72	73	41	60	76	59	52	35	39	37	33	71
1yr (1999/00)	64	70	31	28	56	37	61	42	34	39	38	70
3yr (2001/02)	49	40	35	37	54	38	28	35	23	46	43	76
Proportional change pre-log to 3yr	0.68	0.55	0.88	0.62	0.71	0.64	0.54	1	0.59	1.24	1.30	1.07

*Within treatment comparison of change in frequency count to change in rosette count*

This analysis only considered within-treatment effects and made no comparison between treatments.

The proportional change in frequency count of occupied 2x2m subplots compared to the proportional change in the number of rosettes from pre-logging (0) to 3yrs was significantly different for the logged-only treatment ( $p < 0.05$ ,  $F = 12.79$ ). Rosette numbers increased in this treatment but their distribution decreased across the quadrats. This occurred because *Brunonia* disappeared completely from plots where there were only small numbers of plants (rosettes) but increased in those plots that started with many plants (appendix 4A).

Scarification also caused a significant difference ( $F = 6.66$ ,  $p < 0.05$ ) in the change of occupied subplots from 0-3yrs compared to the change in *Brunonia* rosette numbers over the same period. While both subplot occupancy and plant numbers decreased, the decline in plant numbers over 3 years was greater than the reduction in subplot occupancy suggesting that even the subplots with large numbers of plants pre-treatment were severely affected and had not recovered well over this period.

There was no significant difference between the change in subplot occupancy compared to the change in rosette numbers in the logged-burnt treatment from 0-3yrs. This reflected the greater variability in response of *Brunonia* to this treatment due to incomplete treatment coverage.

There was a significant difference between the change in subplot occupancy compared to the change in rosette numbers in the control from 0-3yrs ( $F=31.1$ ). The increase in plant numbers was greater than the increase in subplot occupancy. Therefore a large number of new rosettes were produced but these were clumped rather than widely dispersed across the quadrats. This corresponded with above average rainfall in the growth period of Oct-Dec 2001 (year 3).

These results reflected how the thickening of the understorey vegetation over time influenced *Brunonia* distribution. Larger clumps of *Brunonia* were not overtaken by other understorey plants and increased their numbers both through new germinants and vegetatively produced rosettes. Isolated plants in the treatment areas, were however, out-competed by grasses and other aggressive understorey species.

#### **5.3.4 Impacts on flowering**

##### *5.3.4.1 Quadrats*

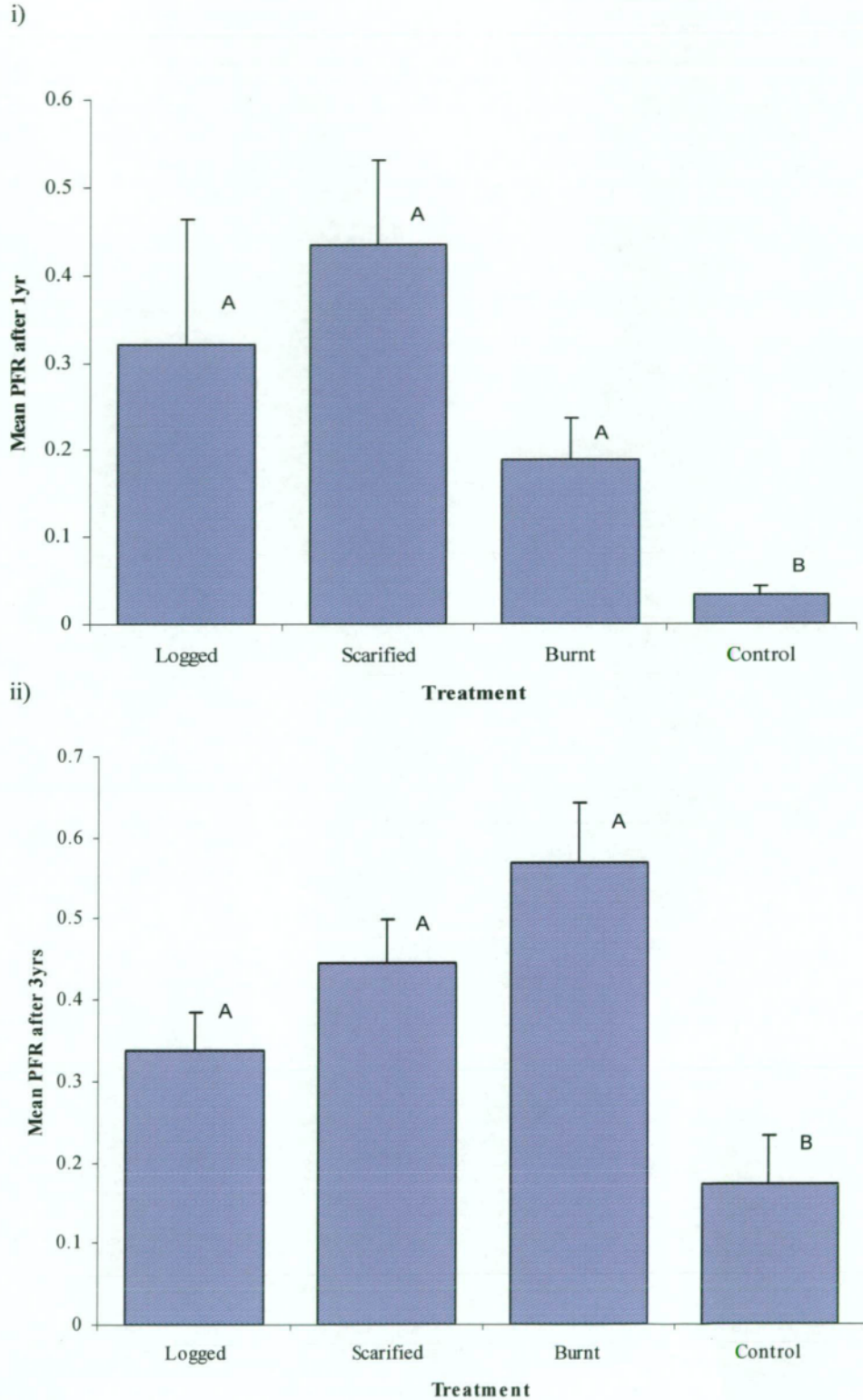
There was no significant difference ( $p<0.05$ ) in the proportion of flowers to rosettes between any of the treatments prior to logging. Flowering was therefore consistent across the study site. However, there was a significant difference among treatments in both the first year after logging ( $F_{3,8}=9.08$ ) and third year after logging ( $F_{3,8}=7.30$ ), (Fig. 5.7). In the first summer following treatment, there was very poor flowering in the undisturbed controls but obvious and relatively abundant flowering on surviving plants in the logged-only and scarified areas. Overall, the logged-burnt quadrats also flowered well (19% of rosettes flowered) but flowering in the actual burnt plots was much poorer (see below). In the third year, flowering at the quadrat level in all treatments remained significantly higher than in the control (Fig. 5.7).

##### *5.3.4.2 Burnt plots*

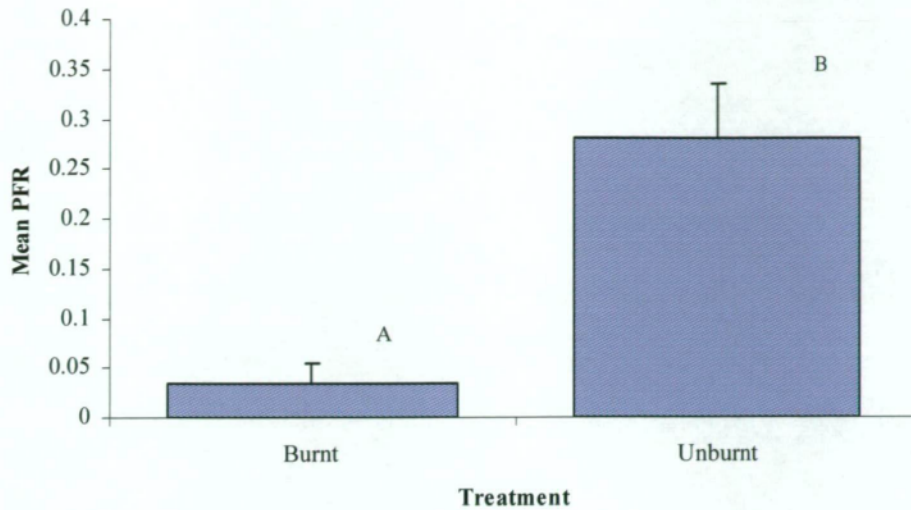
In the first summer after treatment, burnt 4x4m plots showed significantly less flowering per rosette ( $p<0.05$ ,  $F=15.94$ )(Fig. 5.8) when compared to unburnt plots randomly chosen from within the logged-burnt quadrats. The plants in all burnt plots were slow to recover and were not at normal

rosette size by November/December and very few flowered. There was no flowering in the first year following treatment, in plots classified as burnt by high intensity fire. No difference in flowering was detected in burnt plots by the third year. An interaction effect was identified however, where one quadrat in particular flowered very well in unburnt plots but poorly in burnt plots, although this was not consistently reflected in the remaining 2 quadrats.





**Figure 5.7:** Mean proportion of flowers to rosettes (PFR) for 3 logging and silvicultural treatments and a control i) 1yr after treatment and ii) 3 years after treatment. (B=significantly different at  $p<0.05$ ). Different alphabet letters indicate significant differences between treatments.



**Figure 5.8:** Mean proportion of flowers to rosettes (PFR) in the 1<sup>st</sup> summer after treatment for burnt and unburnt 4x4m plots. (B=significantly different at  $p < 0.05$ ). Different alphabet letters indicate significant differences between treatments.

## 5.4 Discussion

### 5.4.1 Experimental design

Care must be taken to interpret the results within the limitations of the experimental design, which contained a form of pseudo-replication that allows valid statistical comparison between locations and not treatments (Hurlbert 1984). Oskanen (2001) disagrees, arguing that inferential statistics can be used to guide understanding of broad changes between treatments and that future similar studies elsewhere may allow for valid meta-analysis of treatment effects. It is on this basis that the rather obvious effects of treatments in this study are reported. While unforeseen influences may have affected different treatment areas (Hurlbert 1984), the site was uniformly flat, had consistent soils and geology and both overstorey and understorey vegetation were consistent across the area. Inferential statistics helped explain broad changes in this study such as the effects of scarification and the lack of flowering in the control compared to the treatments. Ideally, another logging area containing *Brunonia* would have been useful but none were available during the timeframe of this study.

The use of 20x20m quadrats and a non-interventionist approach in the logging treatment provided a realistic application of commercial logging practices in this study but ran a risk of insufficient coverage for some treatments. The coverage of slash across burnt quadrats may have represented a typically sporadic distribution of slash in these types of logging operations but did not provide a clear effect for burning at the quadrat level. The use of 4x4m plots to subsequently analyse burn effect was considered statistically valid, since the location of slash was random across the quadrats, as was the selection of unburnt plots from within the large, 20x20m burnt quadrats.

Future studies may consider using smaller quadrat sizes and actively applying controlled treatments to them. Known quantities of slash, for example, may be applied directly over small plots (2x2m) using an excavator with grab, and then burnt. This would allow greater replication although may not solve the need for completely random interspersation with other treatments. Use of an excavator may allow construction of small firebreaks around burn treatment plots and give enough confidence to intersperse them randomly with other treatments.

Smaller plot sizes may also allow better assessment of the effect of understorey thickening through the use of cover scales. Cover of other understorey plants was recorded in this study at the 4x4m plot level but these were found to be too large to provide meaningful results.

#### **5.4.2 Logging treatment impacts on rosette numbers**

In the first summer after logging and silvicultural treatment, scarification was shown to have caused a significant decline in *Brunonia australis* rosettes compared to other treatments and the control. While the species shows some resilience to even moderate levels of soil disturbance, it was not able to recover to pre-treatment levels after 3 years following heavy mechanical scarification. The fast recovery of other understorey plants, particularly grasses, and *Brunonia*'s apparent poor dispersal ability suggest that it is unlikely to recover to pre-treatment levels for many years.

While burnt patches also resulted in a significant decline in *Brunonia*, as other understorey species took over, the sporadic nature of top disposal burning means that this treatment is unlikely to be

detrimental to the population in the longer term. Potential impacts may be greater if fire coverage is greater than in this study or where there is increased likelihood of dense recovery of bracken, wattle or other higher strata understorey species.

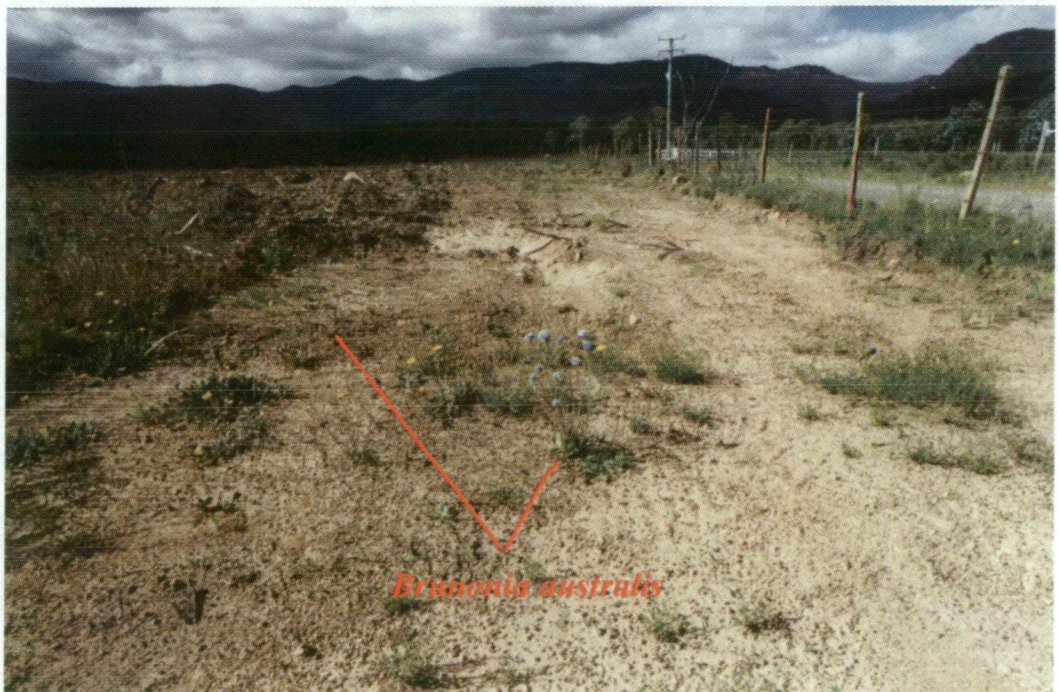
Moderate disturbance from logging is unlikely to cause immediate declines in healthy *Brunonia* populations. Overall numbers of rosettes increased in the logged-only treatment, although there was a decline in some plots that contained few individuals prior to logging, probably because *Brunonia* has greater competitive ability when occurring in larger clumps. The increased light availability after logging and the cessation of grazing to allow eucalypt regeneration permitted dense understorey recovery. The increase in understorey density appeared to be the main restriction on successful longer-term recovery of *Brunonia* in treated areas. In contrast, understorey in the unlogged controls did not increase in density to the same extent and these quadrats displayed increased rosette numbers in the years following grazing cessation, even in plots starting with few individuals. This has been attributed to the retention of the overstorey, maintaining lower light penetration compared to the logged areas, in combination with ongoing low level grazing by native animals and rabbits. However, it was observed that general plant condition was poorer in the controls at the time of data collection with many flaccid leaves and lower levels of flowering. The increase in rosette numbers in year 3 was likely to have resulted mainly from additional (vegetative) rosette production following a spring of above average rainfall (appendix 4B), rather than from new germinants which may have struggled establishing due to understorey competition. The poorer condition of plants was attributed to lower light levels and understorey competition.

*Brunonia* appears to be capable of surviving significant disturbances (Fig. 5.9). Up to 37% of rosettes recovered in heavily scarified quadrats 1yr after treatment. The similar distribution of pre and post-treatment plants in scarified and burnt areas suggested that initial recovery was mainly by vegetative means. Resprouting from relatively thick rhizomes and multiple rosettes observed in some locations further supported this. The Tasmanian Government (1996b) listed *Brunonia* as benefited by roading but it is more likely that some individuals survive roading and then flower prominently in the bare, sunny position on batters where there are few competitors. This was observed in the



Blackwood Creek south population where individuals were noted before and after construction of a firebreak. They were observed regenerating from rhizomes in some of the most heavily disturbed parts of the firebreak (Fig. 5.9). The reasons why some individuals survive such heavy disturbance while many others do not, is unknown. Some nurseries have reported that the plant is sensitive to transplanting so it may be that surviving plants are those that have not had their deeper rhizomes dislodged.

The results are generally consistent with the findings of McIntyre *et al.* (1995) who found that hemicryptophytes (rosette life-forms including *Brunonia*, Raunkiaer 1934), amongst other life-forms, declined in soil disturbed areas. They also determined that species relying on vegetative means of recovery are more likely to be affected by soil disturbance than those that rely on seed, and in particular wind dispersed seed, although responses varied within the hemicryptophyte group, which was not as sensitive as several other life-forms. *Brunonia* displays some sensitivity to heavy soil disturbance but may survive and proliferate in areas of light to moderate disturbance.



**Figure 5.9:** *Brunonia* regenerating on a firebreak in the Blackwood Creek south population.

### 5.4.3 Effects of burning

This study has shown that *Brunonia* can be one of the first plants to appear following a spring burn through resprouting of subterranean parts. The relatively large, soft seed of *Brunonia* is unlikely to survive fire so it is improbable that early regeneration will be via on-site seed as suggested by Adams and Simmons (1994) and the Tasmanian Government (1996b). October burning hindered *Brunonia* flowering in the burnt plots during the following November – January. Vegetative growth was slow, as also noted in the study by Hitchmough *et al.* (1989), with insufficient time for plants to produce flowering stems. This reduction in reproductive vegetative regeneration combined with the increased bracken cover following the spring burn (Tolhurst *et al.* 1992), suggests that late autumn burning is preferable. Delpratt (1996) has reported that *Brunonia* may flower in the first summer following autumn sowing, and so resprouting following an autumn (or winter) burn is also likely to allow flowering later that year. Wark *et al.* (1987) also reported *Brunonia* flowering 1 year after a summer bush fire the previous season.

Purdie (1977) proposed that vegetative recovery following fire is affected by: fire intensity, post-burn soil moisture, plant age, and origin of the regrowth. As recovery in the first year of this study was not significantly different to unburnt sites, none of these factors are likely to have had an important influence. Rather, the significant decline in rosette numbers in burnt plots over time appears to have been caused by dense understorey recovery particularly of overtopping plants such as bracken and wattle. Other populations have been noted to thrive in burnt areas that have grazing stock present, suggesting that it is the competing understorey causing decline not the burn itself. Wark (1997) listed a similar response for *Brunonia* in a forest reserve in Victoria, where the species was present in permanent quadrats 1 and 3 years after wildfire but absent 10 years later. The decline in vascular species richness over time in that study was also linked to increased vegetation cover. The burn at the Bracknell study site was conducted within typical guidelines for fuel reduction although relative humidity may have been higher than the 40-60% recommended by Anon. (1984). However, the higher fuel loads involved with top disposal burning means that milder conditions are preferred to minimize scorch or the chance of escapes.

Fire intensity, as determined by reduction in fuel load, did not significantly affect the response of *Brunonia* in this study. Plants were observed recovering in the hottest burnt areas but greater replication would be needed to examine the effects with more certainty. Fire intensity in this study was only a relative measure and not a quantitative assessment. Intensity is directly associated with the quantity of fuel consumed (Alexander 1982), so the relative assessment of change in fuel volume after burning provided an efficient and inexpensive measure.

#### 5.4.4 Effects of treatments on flowering

Observations on many populations across Tasmania suggest that *Brunonia* require sunny positions. Opening up the tree canopy is, therefore, likely to have encouraged flowering in the first year in all logged areas, other than burnt plots, despite very dry conditions. The reasons for significantly poorer flowering across the control areas in the first summer following treatments may have been due to the combined effect of dry weather, retained overstorey and thickening understorey. During spring of 1999/2000 (the first growth period after treatment) mean monthly rainfall from September to December was approximately 30mm (44%) less than the 38yr average (appendix 4B). Flowering appeared to improve in the controls in the third summer following a spring (2001) of above average rainfall but compared to the logged areas was still likely to have been limited by both the overstorey and understorey competition.

#### 5.4.5 Effects of weed competition

The cover of weeds dramatically increased in the study site following logging and silvicultural treatments (data not presented here). This is a typical response to significant disturbance in these forest types (Williams 1991). Introduced grasses including *Holcus lanatus* (fog grass), *Aira caryophyllea* (Silvery hairgrass), *Agrostis capillaris* (browntop bent), and *Briza minor* (lesser quaker grass) quickly colonized disturbed areas particularly scarified and burnt locations. Other weeds that also increased in cover included *Cirsium vulgare* (thistle), *Centaureum* species, *Senecio jacobaea* (ragwort) and *Ulex europeaus* (gorse). The range of weed species present was typical of dry midlands forest types (Fensham and Kirkpatrick 1989). The proximity of the site to pasture areas, where weed populations are likely to be higher, facilitated the increased cover of weeds (Williams

1991, Yates and Hobbs 1997). Future management of dominant weeds (gorse, ragwort) on the site may require direct herbicide application or manual removal. Targeted research is required to investigate the impact on native understorey diversity and abundance by weed species following logging in these forest types and the best methods to minimize weed invasion.

#### **5.4.6 Other *Brunonia* populations subjected to logging**

Broadly similar results to this study were observed in two other *Brunonia* populations subjected to recent logging. The population at Blackwood Creek north in grassy Inland *Eucalyptus amygdalina* forest, was selectively logged in 1997 and mechanically scarified shortly after. A wildfire burnt the area the following summer (1998/99). The population had been briefly observed prior to operations and was in reasonably healthy condition. In summer 2000/2001, very dense grass recovery severely affected the survival chances of *Brunonia* in the logged/scarified area. The forest had been grazed with sheep for many years but stock had been removed following logging to facilitate eucalypt regeneration. An adjacent patch of *Brunonia* had been retained in a small reserve, possibly 30x80m wide. As for the control areas at the Bracknell study site, there was noticeably less understorey thickening in the untreated reserve and the *Brunonia* in this area was not under the same apparent threat of exclusion by the understorey.

Another population at Westwood beneath grassy inland *Eucalyptus amygdalina* forest displayed similar responses. The population was inspected prior to operations in 1997/98 and was more affected by sheep grazing than the Blackwood Creek site. There was also generally lower understorey plant diversity with a higher cover of grasses. Selective logging was followed by mechanical scarification. A follow up inspection during summer 2000/01 found that *Brunonia* individuals had survived but were few in number and struggling amongst dense grass. The area had been fenced off and grazing stock excluded.

Care needs to be taken not to apply the results of this study to all Tasmanian *Brunonia* populations. While the study site is typical of many populations, others occur on much poorer substrates where understorey dynamics are likely to be different (Kirkpatrick and Gilfedder 2000). The population at



Lefroy had been logged and burnt, probably within 15 years of inspection in summer 2000/01 but was beneath *E. obliqua* on a less productive soil type with different, heathy understorey species that did not appear to exclude the herbaceous flora.

#### **5.4.7 Consequences for silvicultural treatments in inland *Eucalyptus amygdalina* forests**

The results of this study and observations in other similar forest types suggest that mechanical scarification should not be used in grassy inland *E. amygdalina* forests where maintenance of a diverse herb understorey, including species such as *Brunonia australis*, is a desired outcome. Heavy mechanical scarification using root rakes on bulldozers impacts directly on herbaceous plants and encourages dense grass recovery. Where the seedbed is not considered adequate for eucalypt regeneration following logging, alternative methods should be applied. Top disposal burning or low intensity broad scale burning may be suitable but care needs to be taken on sites where bracken, wattle or weed species benefit from fire at the expense of the herbaceous understorey. Orr and Todd (1992) recommend no burning on dry grassy sites.

Recent developments in the use of small excavators for slash heaping may be helpful in sensitive areas or where grass may cause problems (Neyland 2000, Hawkins 2002). Excavators are more easily controlled compared to bulldozers, ensuring only moderate levels of mechanical disturbance through the action of collecting slash into small stockpiles across a coupe. The slash piles can be either burnt at safe times of the year or constructed on bare soil areas in such a way that allows a caging effect for the protection of regenerating eucalypt seedlings from browsing animals. The slash 'cages' may also reduce light availability and therefore help to limit grass competition around regenerating eucalypts growing inside the cages.

Clearfelling should never be used as a silvicultural technique in inland *E. amygdalina* forests (Orr 1991, McCormick 1991). There is a substantial risk that grasses and weed species will overtake the regenerating forest and it would be extremely difficult to rehabilitate should the initial seedling crop fail due to drought, browsing or other reasons. Clearfelling is not regarded as a mimic of natural

disturbance in these forest types and will also severely impact native species recovery to the advantage of weeds (Williams 1991).

The removal of grazing stock from the Bracknell study site and the Blackwood Creek north and Westwood populations following timber operations has allowed understorey thickening which may be detrimental to the long term survival of herbaceous plants with similar life cycles to *Brunonia*. It would therefore be desirable to return sheep to these sites as soon as the height of tree regeneration allows avoidance from grazing (approximately 1.5m, Orr 1991). Several consecutive periods of heavy winter grazing may permit some recovery of the herbaceous understorey through reduction of competing perennial species (e.g. grasses) in winter and subsequent flowering, seed set and dispersal of herbs from spring to autumn. Maximising seedling growth is, therefore, essential to allow sheep back onto the site sooner. Supplementary eucalypt seed sowing in the appropriate season immediately after operations (normally autumn) together with game control would help to facilitate fast regeneration.

This study showed that smaller patches of *Brunonia* may decline following logging and cessation of grazing while larger patches may increase. Therefore, it follows that proposed operations in populations containing few plants should aim to protect those plants in reserves, or to at least avoid disturbance from impacts such as landings, roads or major snig tracks.

## 5.5 Conclusion

While some heavy disturbances, such as scarification, may directly impact *Brunonia* individuals, the long term survival of a population does not appear to be directly related to logging or silvicultural disturbance per se. Rather, it is the recovery and growth of other species, particularly weeds, grass and other colonizers (e.g. bracken) that have a major influence on the long term survival of *Brunonia*, and probably many other understorey herbs and forbs. *Brunonia*, and other understorey species, are capable of recovering from the initial disturbances created by logging practices but cannot compete in the longer term with the more aggressive weeds and grasses which have been benefited by increased light levels and removal of the historic disturbance regime (e.g stock grazing)

that had maintained the community prior to logging. Therefore, the management of the post-logging disturbance regime is as important for the long-term maintenance of species diversity, as the selection of an appropriate silvicultural system.

## 5.6 Acknowledgements

Many thanks to George and Pat Spencer for permitting the study to be conducted on their land and their patience as the project continued over an extended period. Thank you also to Rodney Bye and Peter Huett of Select logging for carefully carrying out the logging operation to the desired prescription. Greg Unwin gave kind assistance at the University of Tasmania, northern campus with the supply of laboratory space and ovens for fuel drying. Phil and Bonnie Spencer of “Sand Park”, generously supplied both long-term and study period weather records. Rachelle Hawkins patiently helped with booking work in the pre-survey of the *Brunonia* population and great dinners upon returning home on late summer evenings.

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## **6. Effect of three silvicultural treatments on eucalypt regeneration in dry, inland *Eucalyptus amygdalina* forest in the Northern Midlands, Tasmania.**

Craig Hawkins

**Abstract** As part of a broader research project examining the impacts of logging on the threatened herbaceous understorey species, *Brunonia australis*, eucalypt regeneration following logging and typical silvicultural treatments was investigated in a dry, grassy inland *Eucalyptus amygdalina* forest. Conventional selective logging was conducted in 1999 reducing the stand to a basal area of approximately 9-12m<sup>2</sup>/ha. Each of three silvicultural treatments (logging only, mechanical scarification, top-disposal burning) was applied over more than 1ha. A regeneration survey and basal area sweep was conducted 27-32months later. Eucalypt regeneration was most successful in the logged/scarified treatment and least successful in the logged-only treatment. In contrast, *Brunonia* responded poorly in the scarification treatment but persisted in higher numbers in the logging only treatment. Available seedbed was important but browsing pressure by native and introduced animals was also a major influence on regeneration success. Symphyomyrtus species (*E. viminalis*) may be preferentially browsed by introduced and native vertebrates influencing the long term species mix of these forest types but further targeted research is required to confirm this hypothesis. Modification of silvicultural techniques involving scarification will be required in Inland *Eucalyptus amygdalina* forests containing *Brunonia* in order to achieve both acceptable eucalypt regeneration levels and maintenance of *Brunonia* populations.

### **6.1 Introduction**

Grassy forest types in the northern Midlands of Tasmania have been heavily impacted since European settlement by land clearing, logging, weed invasion and domestic stock grazing (Fensham and Kirkpatrick 1989; Kirkpatrick and Gilfedder 2000). Inland *Eucalyptus amygdalina* (black peppermint) forest in the Midlands bioregion is one of the poorest reserved communities in Tasmania with only 1700ha (9%) of its current area (19800ha) reserved in 2001 (Forest Practices

Board 2002). Conversion to non-forest is now restricted in this forest type under the *Forest Practices Act (1985)*, as required by the permanent forest estate provisions of the Tasmanian Regional Forest Agreement (Tasmanian Government 1997), but private landowners may elect to harvest timber and regenerate with native species. Selection of effective silvicultural techniques is, therefore, critical for obtaining adequate regeneration and maintaining long term ecological viability in inland *E. amygdalina* forests.

Logging intensities and methods in dry forests in Tasmania have varied considerably over the last 40-50 years (Hickey and Wilkinson 1999). Prior to the 1970's, the lower productivity and higher timber defect of drier forests allowed only selective harvesting for sawlogs and other minor products. With the introduction of the export pulpwood industry in 1971, improvements in stand productivity were attempted through the use of clearfelling, burning and sowing (Hickey and Wilkinson 1999). As the limitations of these operations became apparent by the 1980's (e.g. Bowman and Jackson 1980), various partial logging systems were trialed (McCormick and Cunningham 1989). The majority of logging operations in dry forests were partial harvesting systems by the 1990's.

The success of different logging and silvicultural techniques for regenerating dry forests has been recently examined by Pennington *et al.* (2001) in the south east of Tasmania, and the efficacy of techniques of strip clearfelling, clump retention and ground preparation using excavators has been examined by Neyland (2000). Most of the literature, however, relates to work in dry forests of eastern and southeastern Tasmania and, while likely to be relevant, are not based on data from the dry northern inland forests.

This study reports the regeneration success in a dry grassy, inland *E. amygdalina* forest in the northern Midlands following partial harvesting and three typical silvicultural treatments (logging only, logging and post-logging scarification, logging and post-logging top-disposal burning) as part of a broader research project on the threatened species *Brunonia australis*. An understanding of the effects of silvicultural treatments on *Brunonia* would not be worthwhile without an appreciation of



the effectiveness of those treatments in achieving the desired aim of acceptable eucalypt regeneration.

## 6.2 Method

### 6.2.1 Study site

The study site was a 15ha privately owned, 'inland *Eucalyptus amygdalina*' (black peppermint) forest on Tertiary alluvial soil, near Bracknell (GR 493200 5390700 Cluan 1:25000 mapsheet). Topography was flat, elevation approximately 210m a.s.l. and mean annual rainfall was 820mm with a winter peak. The forest was scheduled for selective logging in 1999 and was chosen principally to examine the impacts of silvicultural techniques on the threatened species *Brunonia australis*, which is reported elsewhere. The stand was dominated by mature and over-mature *E. amygdalina*, with occasional *E. viminalis* (white gum). Past disturbances included firewood cutting and light grazing by sheep and cattle, which ceased shortly before commencement of logging. No fire was known to have occurred in the area for more than twenty years. Understorey was generally open and dominated by herbs and grasses with frequent denser patches of *Pteridium esculentum* (bracken). Floristically, the site was in relatively good natural condition with weeds limited to a few patches of gorse (*Ulex europaeus*), some thistles (e.g. *Cirsium vulgare*), grasses (e.g. *Holcus lanatus*) and other species (e.g. *Centaureum* sp.).

### 6.2.2 Pre-logging

During the pre-logging survey for *Brunonia* at the study site, basal area sweeps of eucalypts and regeneration surveys were conducted every 20m along parallel transect lines 50m apart, with the first line located randomly. The aim was to determine the levels of existing regrowth at the site and stand uniformity. Basal area was calculated using a 4 m<sup>2</sup>/ha optical wedge and the count of each species was recorded. The number of eucalypt advance growth <1.5m and >1.5m in height, was recorded by species in a 16m<sup>2</sup> circular plot.

### 6.2.3 Treatments

Three 1.8 – 2 ha squares were subjectively located across the main *Brunonia* distribution. An additional 1.8-2 ha control square was located subjectively in a contiguous area of the *Brunonia* distribution but which would not interfere with logging. One hectare was determined as the most

practical area for each treatment to be effectively and safely conducted within, and a suitable area to monitor eucalypt regeneration (Pennington and Ellis 1997). Each of the three 1 ha areas to be harvested was randomly assigned a harvesting/regeneration treatment. Three logging and silvicultural treatments were chosen including logging only, logging and post-logging scarification, logging and slash burning. Conventional logging commenced in April 1999 using manual tree falling and snigging with a rubber-tyred skidder. The logging crew was instructed to retain a basal area of approximately 8-12m<sup>2</sup>/ha. Scarification was conducted on 31 May 1999 using a front mounted root rake on an International TD15 bulldozer. Scarification was aimed at removing all vegetation and debris back to bare earth over more than 50 percent of the total area except within about 2m of retained trees. Top disposal burning was conducted in mild conditions on 20 October 1999. No additional regeneration works involving seed application or browsing control were undertaken during the course of the study.

#### **6.2.4 Postlogging**

A modified version of the standard Tasmanian regeneration survey (Forestry Commission 1991b) was used to assess the treatments for regeneration success and residual stand stocking in January 2002, 32 months after logging and 27 months after top disposal burning. Despite the selective harvesting nature of the operation the success of regeneration was of utmost importance due to the forest owners desire to undertake a second stage overstorey removal operation. Each treatment was intensively surveyed with 56 x 16m<sup>2</sup> regeneration plots. Plots were located every 15 m along transect lines spaced 15 m apart. The first point was located 5m in from the corner of the area. The resulting survey covered just over one hectare (110 x 110m) but the treatment area had in each case extended at least 20m past the boundary of the survey (~2ha).

For each plot, the number and relative health of eucalypts <1.5m and >1.5m in height was recorded. Presence of one or more seedlings constituted a stocked plot. Unhealthy individuals were subjectively assessed as plants affected by heavy browsing, insect attack or severe leaf discolouration or other defect. The tallest seedling in each plot was also recorded to the nearest 5 cm. Plots were recorded as burnt if more than 25% showed recently burnt debris or ground charring indicating at least a medium to hot burn where litter layers were consumed and bare seed bed

provided (Wilkinson and Jennings 1994). A plot was considered scarified if more than 50% of it showed mechanical soil disturbance. Coppice was infrequent across the study area and not considered as part of the regeneration.

Basal area was measured as above, every 30m on every second line (30x30m) giving 16 measures across the sample area for each treatment.

### 6.2.5 Analysis

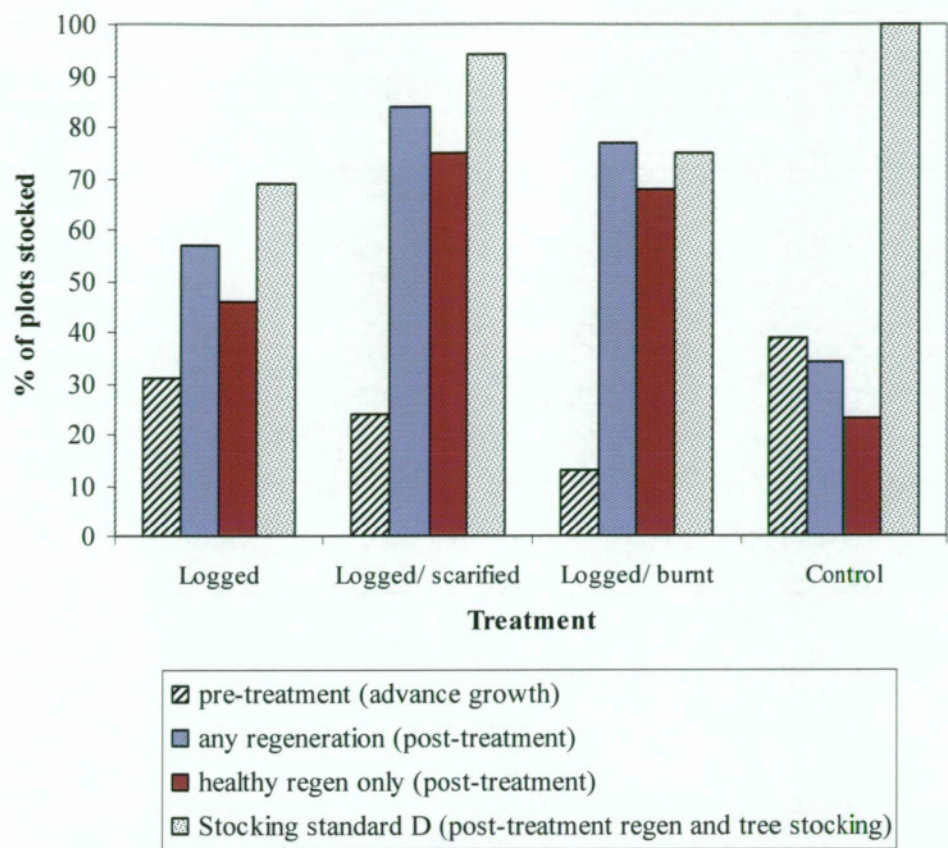
Regeneration success was measured in terms of percentage of plots stocked. A minimum of 65% was considered adequate regeneration to represent stocking (Pennington *et al.* 2001).

Mean maximum seedling height was compared between treatments using a 1-way ANOVA with a Bonferroni *post hoc* comparison and average number of seedlings per plot was compared using a 1-way ANOVA with a Dunnett T3 *post hoc* comparison, in SPSS – version 10.0 statistical package.

## 6.3 Results

### 6.3.1 Pre-survey

The site was relatively uniform across treatment areas as expected given the consistent geology, flat topography and homogenous overstorey and understorey. Advance growth was sparse with slightly fewer (12% of plots stocked) plants recorded in the logged/burnt treatment area and slightly more (40% of plots stocked) in the control (Fig. 6.1). The range of percentage stocking was considered to be relatively uniform between treatments. No *E. viminalis* advance growth was recorded in plots. Advance growth over 1.5m was negligible in all areas and was given no further consideration. The proportion of *E. amygdalina* to *E. viminalis* in basal area terms was consistent across all treatments (Table 6.1) with *E. amygdalina* comprising 80-90%.



**Figure 6.1:** Regeneration success and stand stocking 27-32 months after 3 logging and silvicultural treatments and a control measured by % of plots 1) stocked with any regeneration (n=56); 2) stocked with healthy regeneration (n=56) and ; 3) conforming to stocking standard D (Forestry Commission 1991b) (n=16) compared to the % of plots stocked with eucalypt advance growth pre-treatment (n=15-19).

6.3.2 Effect of treatments

Basal area was reduced to between 9-12.5 m<sup>2</sup>/ha in all treatments (Table 6.1). Species proportions in the basal area remained broadly uniform with a possible proportional decrease in *E. amygdalina* in the logged/scarified treatment. The slight change in the control is likely to be a result of sampling error.

**Table 6.1:** Stand basal area and proportion of *E. amygdalina* and *E. viminalis* in the overstorey before and after logging for three silvicultural treatments and a control.

Measure	Treatment			
	Logged	Logged/scarified	Logged/burnt	Control
Original basal area (m2/ha)	32.9	26.6	30.1	32.7
Retained basal area (m2/ha)	11.5	12.3	9.5	33.3
Original <i>E. amygdalina</i> / <i>E. viminalis</i> BA %	82/18	81/19	80/20	88/12
Residual <i>E. amygdalina</i> / <i>E. viminalis</i> BA %	89/11	68/32	76/24	95/5

Mechanical disturbance was difficult to confirm due to understorey recovery but was estimated at occurring at least partially in 35-60% of plots in logged-only and logged/burnt treatments and 10% of plots in the logged/scarified treatment. Up to 21% of plots were recorded with heavy slash in the logged-only treatment (Table 6.2) but the majority of slash piles were congregated or burnt in the other two treatments. Scarification had a high coverage of approximately 50-75% and burning of at least medium intensity was estimated to cover approximately 40% of the treatment area.

**Table 6.2:** Percentage of plots subjected to mechanical disturbance, heavy slash, scarification or medium to high intensity fire for three silvicultural treatments.

Percentage of plots with:	Treatments		
	Logged	Logged/ scarified	Logged/ burnt
Some mechanical disturbance (non scarified)	35-60%	10%	35-60%
>50% heavy slash	21%	7%	0%
>50% scarified	-	75%	-
>25% burnt	-	-	40%

### 6.3.3 Stocking and regeneration height

Regeneration success is summarized in figure 6.1 and table 6.3. The overall potential for regeneration of eucalypts, irrespective of recorded health was higher in the logged/scarified (84% of plots stocked) and logged/burnt (77% stocked) treatments than the logged-only treatment (57% stocked). Heavy slash piles restricted the development of seedlings in many plots in the logged-only treatment. Controls appeared to maintain a stocking consistent with pre-treatment measures. Within the logged/scarified treatment, 93% of plots that were recorded as successfully scarified (>50% disturbed), were stocked with regenerating seedlings. In the logged/burnt treatment, 71% of plots successfully burnt (>25% burnt) were stocked with seedlings.

Individual lignotubers and seedlings recorded as unhealthy were invariably heavily browsed. When health was considered the stocking rate declined in all treatments and the control but remained at relatively high levels in the logged/scarified and logged/burnt treatments. Under stocking standard D of Forestry Tasmania guidelines (Forestry Commission 1991b), which takes into account standing trees, all treatments were relatively well stocked. The logged-only treatment was the lowest with 69% of plots stocked.

**Table 6.3:** Summary of regeneration success for three silvicultural treatments and control in an inland *E. amygdalina* dry sclerophyll forest 27-32 months after treatment.

Measure	Treatment			
	Logged	Logged/ scarified	Logged/ burnt	Control
1) No. of plots (n)	56	55	56	56
2) Mean maximum seedling ht. (m)	0.41	0.41	0.32	0.35
3) Mean no. <i>E. amygdalina</i> (<1.5m) / stocked plot	2.4	3.8	3.0	2.6
4) Mean no. <i>E. viminalis</i> (<1.5m) / stocked plot	0.0	0.0	1.0	0.0
5) % seedlings <i>E. amygdalina</i> / <i>E. viminalis</i>	100 / 0	100 / 0	99 / 1	100 / 0
6) % seedlings healthy	69%	67%	64%	45%
7) Total number of seedlings in plots	78	177	129	48
8) Equivalent no. of seedlings per ha	871	2011	1440	536

There was no significant difference ( $p=0.05$ ) in mean maximum seedling height between treatments (Table 6.3) but average number of seedlings per plot was significantly higher for the logged/scarified and logged/burnt treatments than in the control. Scarified plots also had a significantly higher number than in the logged-only treatment.

Good seedbed conditions had virtually disappeared within the 32 months since logging in the logged-only treatment due to grass, bracken and other understorey regrowth. The logged/scarified and logged/burnt treatments maintained a small percentage (<10-15%?) of seedbed but were gradually being revegetated. Observations during regular visits between logging and survey suggested that there was reasonable seedbed availability for up to 20 months after completion of operations.

## 6.4 Discussion

### 6.4.1 Stocking

The logged-only treatment achieved only 57% of plots stocked with eucalypt regeneration compared to the logged/scarified (84%) and logged/burnt (77%) treatments. Regeneration in the latter two was clearly favoured by the improved seedbed conditions but slash piles and dense grass or bracken combined to reduce the seedbed available in the logged-only treatment. A level of 65% of plots stocked with regeneration was considered a minimum acceptable level and was used by Pennington *et al.* (2001) for a seed tree retention system in dry forests. The higher basal area retention in this

study suggests that it is a demanding target but as the expectancy is to achieve regeneration beneath the retained stand it is a desirable target. The results are comparable to those of Pennington *et al.* (2001) who found the fraction of 16 m<sup>2</sup> plots stocked after 3 years as approximately 70-80% for post-logging scarification, 60% for post-logging burn and 50% in logged-only treatments. Pre-harvest scarification was the most successful with over 80% of plots stocked.

In terms of total seedling stocking per hectare (Table 6.3), the logged/scarified (2011/ha) and logged/burnt (1440/ha) treatments again reflected much better regeneration than the logged-only treatment (871/ha). Given the high basal area retention in this study (~9-12m<sup>2</sup>/ha) an acceptable stocking could be in the order of 1200-1500 individuals/ha provided they are not clumped. In comparison, Pennington *et al.* (2001) proposed 2500 stems/ha to be an acceptable regeneration stocking for their seed tree retention prescription. The significant reduction in the number of overstorey trees in a seed tree retention system necessitates a much higher seedling stocking rate to maintain maximum productive capacity of the site. Both lignotubers and new seedlings contributed to regeneration in all treatments given that the pre-treatment stocking levels (Fig. 6.1) would have been virtually all lignotubers. Squire and Edgar (1975 unpubl.) also reported that lignotubers alone would not have provided sufficient regeneration stocking in a Victorian dry forest and recommended provision of suitable conditions for seedling germination.

An indication of overall forest stocking, including standing trees, was made using a modification of the Tasmanian stocking standard (D) for partially harvested forests (Forestry Commission 1991b). A level of 80% of plots stocked was considered an appropriate target based on the standard. Only the logged/scarified treatment (94% of plots stocked) and the control (100%) could be considered fully stocked forests using this measure. As the method required basal area calculation, a small sample size (n=16) across the survey area may have biased the results for the logged-only and logged/burnt treatments, which missed the target by only 2 and 1 plots respectively. Orr and Todd (1992) argued that an 80% standard was more appropriate to wet forests and that a lower target for drier forests was acceptable. The outward appearance of all treatments was one of acceptable stocking with occasional open patches containing less than desirable levels of regeneration. The results of this study are not

directly comparable to typical regeneration surveys using stocking standard D, as the scale of the survey is normally larger than 1 hectare recognizing the natural heterogeneity and clumpiness of dry open forests.

Improved seedbed conditions are likely to be responsible for a better level of eucalypt germination in the logged/scarified and logged/burnt treatments (Stoneman 1994). The logged/scarified treatment had the largest area of exposed seedbed and 93% of plots actually subject to scarification were stocked. Research on scarification in *E. delegatensis* forests has suggested that the variation in microsites provided through furrows and ridges allows more opportunities for successful germination and development of eucalypt seedlings (Battaglia and Reid 1993). Additional recruitment is possible over the next few years in all treatments (Orr and Todd 1992) but the diminishing seedbed in the logged-only treatment will limit success. The increase in grass cover was noted across all treatments except the control and is attributed to the removal of the overstorey (Forestry Commission 1991a).

The very dry and hot spring/summer of 1999/2000 may have also affected seedling survival in the first season after logging. The excellent growing conditions in the following 2 years (2000/01, 2001/02) may have allowed better recruitment in the logged/scarified and logged/burnt treatments, which retained a higher level of acceptable seedbed than the logged-only treatment after the first year.

The lack of *E. viminalis* regeneration is of concern with only 2 plots in the logged/burnt treatment containing the species. *E. viminalis* constituted 10-20% of the pre and post-logging basal area of the stand. The seed crop was not as consistent on heads observed during logging but any seedlings observed across the study area were always severely browsed. In 1999 the landowner planted a dozen *E. nitens* at the study site but all were observed heavily browsed shortly after and could not be relocated in January 2002. The brushtail possum (*Trichosurus vulpecula*), Bennett's wallaby (*Macropus rufogriseus*), Tasmanian pademelon (*Thylogale billardierii*) and rabbit (*Oryctolagus cuniculus*) are known to be major browsers of eucalypts in Tasmania (Neilsen 1990; Orr 1991;



Bulinski and McArthur 2000) and all of these species were observed at the study site. Large populations of brush-tailed possums, in particular, are known to occur in the study area, which is surrounded by cropping land and pastures, but macropod and rabbit populations were not considered high (G. Spencer, landowner, pers. comm. 2002). Browsing is likely to have been the single most important factor in the initial success of regeneration in the area (Orr and Todd 1992). It is difficult however, to determine whether preferential browsing caused higher losses to *E. viminalis* than *E. amygdalina* or whether initial establishment of *E. viminalis* was lower for other reasons. McArthur and Turner (1997) showed preferential browsing of eucalypt species by captive brushtail possums with *Symphyomyrtus* species (*E. nitens*, *E. globulus*) likely to be preferred over *Monocalyptus* (*E. regnans*, *E. delegatensis*). Assuming preferences hold true across the subgenera it is reasonable to expect that preferential grazing by brush-tailed possums may have impacted *E. viminalis* (*Symphyomyrtus*) more than *E. amygdalina* (*Monocalyptus*). The loss of all *E. nitens* (*Symphyomyrtus*) planted at the site further supports this. The brush-tailed possum population at the site was relatively small 30 years ago (G. Spencer pers. comm.) and was unlikely to have substantially influenced the species mix that existed prior to logging in this study. The population explosion of brush-tailed possums in the last 2-3 decades since cessation of the possum fur trade, particularly in forests surrounded by pastures and cropping land (Kirkpatrick and Gilfedder 1999, Gilfedder *et al.* 2003) may have important implications on the future species mix of these forests following logging or other disturbances. Preferential grazing has also been shown to occur for certain macropods (Montague 1994) including the Tasmanian pademelon (Lawler and Foley 1999) and also for rabbits (O'Reilly and McArthur 2000). While current research efforts on browsing of eucalypts centre on trees of greater commercial importance (e.g. *E. nitens*, *E. globulus*) further research is also required into whether browsing influences the species mix following logging in drier forests. The use of fenced browsing indicator plots would be of benefit in a future study.

#### **6.4.2 Growth rates**

Animal grazing may have also contributed to the slow seedling growth rates observed with a mean maximum seedling height for plots of approximately only 0.3-0.4metres for all treatments almost 3 years after logging. Interestingly, this was not significantly different from the controls. Healthy

plants up to 0.8-1m+ were observed in all treatments but heavily grazed individuals and newer seedlings kept the averages down.

In addition to grazing and grass competition, growth rates of regeneration in dry grassy forests may also be affected by retained overstorey (Orr 1991, Orr and Todd 1992). Average retained basal areas of 9.5-12.3m<sup>2</sup>/ha for this study may have had some influence on regeneration growth rates.

McCormick and Cunningham (1989) however, suggest up to 20-25 trees per hectare in grassy *E. amygdalina* forest on granites, does not suppress seedling growth and has the added benefit of reducing grass re-invasion. Battaglia and Wilson (1990) found in high altitude *E. delegatensis* forest that seedling height growth was negatively correlated to retained basal area, particularly over 12m<sup>2</sup>/ha. Squire and Edgar (1975, unpubl.) found regeneration was restricted with retained basal areas over 11.5 m<sup>2</sup>/ha in mixed species dry forests in Victoria. Suppression of eucalypts is also correlated with distance from mature stems with better seedling growth in the larger gaps (Florence 1996). Allelopathy and soil water relations as affected by the overstorey, have been found as possible causes (Florence and Crocker 1962; Bowman and Kirkpatrick 1986).

The combination of factors influencing regeneration growth means that at current growth rates, without additional intensive game control, it is likely to be at least another 4-5 years before sheep should be put back into the logged area. This makes a total of 7-8years since logging but to achieve a consistent height across the site above sheep grazing level, given as 1.5m by Orr (1991), an even longer period could be required.

Orr and Todd (1992) recommend that unless required for hazard reduction, burning of heads (top-disposal) should be avoided in dry grassy forests. The 'cage' effect of the felled crowns helps protect regeneration from browsing. Grass does not readily re-invade where there has been a high intensity burn (Forestry Commission 1991a) but the detrimental impact of hot burns on retained trees and possibly on soil properties (Bowman and Jackson 1980) makes this option undesirable in partially logged forests. Nevertheless, where burning can be conducted to avoid canopy scorch and stem damage, as in carefully conducted top disposal burning, the localized ash-bed may still be important

for regeneration (Florence 1996). Pennington *et al.* (2001) found that pre-logging scarification was the most successful treatment for a range of dry forest types. The combination of the caging effect of the crown and the fact that it was felled onto a receptive seedbed permitted better regeneration than other treatments including burning and logging disturbance only. Post-logging scarification was also found to be relatively successful compared to other treatments. Pre-logging scarification or more effective browsing control may have been the best option for eucalypt regeneration in the Bracknell study site due to the high level of browsing observed.

The lack of replication is a limitation of the study. This would be offset somewhat, in terms of effects between treatments, by the uniformity of the study site. Observations by the author for selective logging in other similar forest types in the Northern Midlands suggests that sufficient mechanical disturbance followed by seed sowing is generally a reliable method of achieving regeneration. Regeneration, however, may be slow growing and recruitment episodic and is best assessed at least 3-5 years after logging.

#### **6.4.3 Selection of Silvicultural Technique for Dual Management Objectives**

While post-logging scarification provided the best opportunities for eucalypt regeneration it also appears to have had the biggest short-term impact on the *Brunonia australis* population (chapter 5) and probably a range of other understorey species. Alternative methods to broad scale bulldozer scarification need to be considered in Inland *Eucalyptus amygdalina* forests to meet the dual objectives of achieving eucalypt regeneration and maintaining threatened native understorey species. More controlled forms of scarification may be used such as excavator based methods which enable identification and protection of important patches of understorey vegetation. Alternatively, where future timber production is not a high priority of the landowner selective logging only followed soon after by eucalypt seed sowing on disturbed areas (snig tracks) may provide both adequate forest stocking and acceptable levels of disturbance to understorey plants.

## 6.5 Conclusion

Regeneration obtained in this study was found to be most successful in the post-logging scarified treatment. Regeneration was within acceptable limits in the logged/burnt treatment but inadequate in the logged-only treatment. Heavy browsing by native animals is suspected to have been the major factor in the failure of the logged-only treatment and for the slow growth rates observed in all treatments. Poorer seedbed availability was also a major factor in the logged-only treatment. Preferential browsing may have severely affected the regeneration of *E. viminalis* in all treatments although it may have also had a poorer seed crop and a less successful germination rate than *E. amygdalina*. At current growth rates, sheep grazing may need to be restricted from the area for a total of 7-10 years following logging.

## 6.6 Acknowledgements

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## **7: Summary of Findings and Discussion of Recommended Management Options for *Brunonia* Populations in Tasmania**

The following summarizes the main findings of this thesis and discusses appropriate management options for the maintenance of the Tasmanian *Brunonia* population.

### **7.1 Growth and reproduction**

Appropriate management of *Brunonia* populations in Tasmania will vary across its range depending on individual site characteristics. A number of broad conditions suit the species and it is not highly site specific or sensitive to small changes in environmental conditions like other threatened flora such as *Euphrasia* spp. (Potts 1997).

Preferred site conditions for *Brunonia* are:

- well-drained sandy soils
- elevations below 350m
- latitudes north of about 42°00'
- low understorey competition, although it may persist for several years in heavier competition through persistent underground parts that re-shoot when the competing species are reduced
- sunny positions where plants in higher strata are sparse.
- most populations are found in Inland *Eucalyptus amygdalina* forests

This thesis has collated and reported for the first time a range of reproductive characteristics for *Brunonia australis* in Tasmania. It is expected that most of these are also applicable to mainland populations. They include:

- Germination occurs readily under a range of conditions with no specific dormancy mechanism detected.

- *Brunonia* seed does not persist in the soil for extended periods, most seeds either germinate or become unviable less than 6 months after shedding.
- For one population, an average 71 florets occurred on typical 20mm diameter flower heads with an average 59% producing viable seed.
- Seed dispersal capability by wind and animal attachment is poor and typical dispersal distances estimated at <3-4m, accounting for the typical clumped distribution
- Flowers are pollinated by a range of common insect vectors
- Flowering in one Tasmanian population peaked in early to mid-December with a maximum range from about late November to early March. Flowering period varied for mainland populations.
- Summer flowering may occur in the first year following autumn/winter germination.
- New rosettes may be developed through production of underground rhizomes.
- Poor seed storage and dispersal capability suggests the species will not naturally reinvade an area where the population has been destroyed.

## 7.2 Conservation status

More than 58 populations of *Brunonia* were known at the time of thesis compilation. One of the practical advances made from this study was the detailed analysis of historical population records and the large number of additional populations discovered. The Threatened Species Unit (Department of Primary Industry Water and Environment) has been forwarded accurate records of locations and 49 specimens from new areas were submitted to the Tasmanian herbarium. While such a large number of populations may normally exclude a species from listing on the Threatened Species Protection Act (1995), the high proportion of small, fragmented and at risk populations (>50%) suggests that *Brunonia* should remain on the list, as further declines are likely. Downgrading from the 'vulnerable' category to 'rare' would be reasonable.

Threatening processes continue in many *Brunonia* populations. The main processes threatening Tasmanian populations determined in this study were:



- lack of appropriate disturbance
- heavy summer grazing
- roadside maintenance
- weed invasion
- logging
- clearing (now largely restricted in relevant forest types)

Arcview modeling of potential habitat suggests that more populations will be found across the range of the species. Further review of conservation status should only be made if new, large populations are confirmed. Maps of known populations have been attached as appendix 1E.

A listing statement as required by the Tasmanian *Threatened Species Protection Act (1995)* for all listed threatened species was prepared and is included as appendix 1F.

The conservation of *Brunonia australis* needs to be considered at the broader level of community reservation. The review of populations in this study indicated that over 70% of populations occurred in grassy Inland *Eucalyptus amygdalina* forests, a severely depleted forest community requiring additional reservation to meet the targets of the Regional Forest Agreement (RFA),(Tasmanian Government 1996a). Several populations have been recently formally reserved at Powranna, Brushy Rivulet, Lefroy and Franklin Rivulet following implementation of the RFA although only Powranna is Inland *E. amygdalina*. Management agreements between the government and private landowners have also recently reserved two populations in Inland *E. amygdalina* forest (near Carrick and Cressy). Appropriate management and disturbance regimes are required in these reserves to help maintain populations of not only *Brunonia*, but also other herbaceous understorey species.

## 7.3 Response to disturbance

### 7.3.1 Grazing

This study found that:

- winter grazing (by sheep) was highly beneficial for *Brunonia* because of the reduction of competing understorey species during its dormant period and subsequent prolific growth, flowering and seed set in spring/summer.
- mean inflorescence height was greater in ungrazed and winter grazed areas compared to summer grazed areas

Sheep grazing from about late March to September in grassy forests of moderate fertility is beneficial to *Brunonia* and may lead to an increase in cover of the species due to reduced competition. Many of the populations in grassy *E. amygdalina* forest in the northern midlands region are subject to sheep grazing. For areas where a relatively large patch of forest adjoins an unfenced grazing paddock, the preference of sheep to graze in the open during spring/summer when feed is plentiful is likely to lead to an effective winter grazing regime in the bush. This may partly explain why *Brunonia* has persisted in relatively large numbers in some areas even when sheep have had access to the bush all year round. Grazing, fire or slashing may be effective if used during *Brunonia*'s dormant period over autumn/winter, but may also encourage weed introduction or, in the case of fire, proliferation of species such as bracken (*Pteridium esculentum*) or wattle (e.g. *Acacia dealbata*).

Fensham and Kirkpatrick (1989) demonstrated that restriction of grazing in infertile situations permitted higher species richness but on fertile sites grazing was required to maintain higher richness. Leigh and Holgate (1979) also suggest that the drier and more infertile a site is, the more likely grazing will have a detrimental affect on the vegetation. Persistence of *Brunonia* populations in Tasmania reflects this proposition with lower fertility areas such as Lefroy and Epping Forest containing healthy populations despite no or relatively infrequent grazing by domestic livestock. It is therefore recommended that autumn/winter grazing regimes be encouraged on grassy sites of higher

fertility, which make up a large proportion of the Tasmanian distribution, but discouraged in the drier, poorer sites (Table 7.1).

### 7.3.2 Burning

Observations in this study found that *Brunonia*:

- persisted in burnt areas through survival of underground parts
- was disadvantaged in the logging study area where burning coupled with grazing restriction permitted dense understorey growth particularly of higher stratum species such as *Pteridium esculentum* (bracken) and *Acacia dealbata* (silver wattle)
- was prolific in other burnt areas where grazing was maintained or understorey thickening did not occur
- was unable to flower in the first summer after spring burning

Kirkpatrick *et al.* (1988) suggest that fire may be a useful disturbance factor for maintenance of *Brunonia* populations, probably referring to populations in grassy Inland *E. amygdalina* forest types. Surprisingly, the majority of landowners with *Brunonia* populations surveyed in summer 2000/01 reported few fires in the last 20 years. The two that had been recently burnt appeared to have healthy *Brunonia* populations (Lefroy and Carrick East) but at Carrick the area was also regularly grazed. Lunt (1997) found that frequent fire in grassy forests and grasslands maintained a different suite of species, including threatened species, than in unburnt sites. Lunt and Morgan (1999), on the other hand, found after 10 years of grazing exclusion in a grassland reserve in Victoria that occasional burning encouraged colonizing species, including many weed species such as thistles that were previously controlled by grazing. Such responses are dependent on species present and surrounding the area or the likelihood of species introductions by other means (e.g. farm machinery, vehicles). As many *Brunonia* populations are in remnant forests surrounded by highly disturbed areas such as farmland, the risk of weed invasion is high when the forest floor is disturbed. This was observed in the logging study where a higher cover of weed species, including fog grass (*Holcus lanatus*), thistle (*Cirsium vulgare*), ragwort (*Senecio jacobaea*), brown-top bent (*Agrostis capillaris*), silvery hairgrass (*Aira caryophyllea*) and silk grass (*Vulpia bromoides*) occurred following burning,

scarification or other mechanical ground disturbance. In contrast, following logging and burning in the *Brunonia* population at Lefroy Forest Reserve (recently declared) there was only a low cover of weed species despite a high cover of bare ground years after these disturbances. The large size of the surrounding forest reserve, low fertility and remoteness from weed seed sources clearly helped.

Fire is an important ecological factor in many grassland environments (Duffey *et al.* 1974; Lunt 1997; Yates and Hobbs 1997; Kirkpatrick 1999, Morgan 1999) but the benefits of competition reduction through winter or spelled grazing may not be replicated by fire. Belsky (1992) found that early season fire on grasslands in Tanzania had few effects on individual species cover compared to grazing, which had both larger positive and negative effects. Care should, therefore, be taken when areas are reserved that have been historically subject to grazing as has occurred over a number of *Brunonia* populations (e.g. Powranna, Carrick). Reliance on burning as a disturbance regime may change the understorey dynamics if not associated with at least occasional autumn/winter grazing.

Frequency of burning is also an important factor with herbaceous species often disadvantaged by long fire intervals (Lunt 1994, Morrison *et al.* 1995, Morgan 1999). Morgan (1999) found that annual burning in *Themeda triandra* grasslands in south-eastern Australia was less likely to cause a decline in species richness than burns at greater than 3 year intervals. Lunt (1994) found that several grassland species flowered poorly after only 2 years from the last burn due to thick grass recovery and that flowering was better for areas burnt only 6 months previously. However, the fact that many Inland *Eucalyptus amygdalina* forests in Tasmania are remnant, frequent burning may encourage weed proliferation as discussed above. Grazing may, therefore, be the better option in most grassy forest situations, despite Lunt's (1997) assertion that some sites need to be burnt to maintain regional species diversity.

In contrast, too frequent burning in Tasmanian heathy dry forests on sandy soils will lead to an increase in bracken and will decrease species richness (Duncan 1999) because high fire frequencies repeatedly destroy plants in these communities before they reach reproductive maturity (Wark *et al.* 1987). Care is therefore recommended for use of fire in coastal *Eucalyptus amygdalina* forests

containing *Brunonia*, as found in populations from the upper west Tamar to Moriarty region. While heath species can also overtop *Brunonia* populations, they would not become detrimental as quickly as development of thick bracken cover. Such an impact can be observed at Native Point Nature Reserve in the east Tamar region where very thick bracken cover has caused reduced species richness in otherwise suitable habitat for herbaceous species such as *Brunonia*. In order to limit impacts on species diversity in heath areas, a fire frequency of 5-10 years is recommended for sites containing *Brunonia* as found in populations at Frankford Rivulet, Moriarty and Exeter.

Season of burning may also be important with autumn fire reported as more beneficial to herbaceous vegetation in a dry sclerophyll forest in southeastern Australia than spring fire (Tolhurst *et al.* 1992). Bracken (*Pteridium esculentum*) cover was found to increase after spring burning but only maintain pre-burn levels after autumn burning. Heavy bracken recovery was noted in some spring burnt patches in this study including the logging study. Where fire management is undertaken in areas containing both *Brunonia* and bracken, low frequency autumn burning may therefore prove the best option, in order to minimize the potentially detrimental increase in bracken cover. Furthermore, spring burning (October) in the logging study, significantly reduced *Brunonia*'s ability to flower the following summer, as plants did not have enough time to recover and produce flowering stems. Lunt (1994), however, cautions that annual autumn burning in Victoria may cause declines in species such as the orchid *Diuris punctata*. On balance, regular autumn burning at a 2-4 years frequency is a useful target for those grassy areas where fire is the preferred tool for biomass reduction.

### 7.3.3 Effects of logging on *Brunonia*

The main findings on the impacts of logging on *Brunonia* in this study were:

- scarification had a greater impact on the species than other treatments (logging only, logging/top-disposal burning and no logging) over a 3 year period.
- burning combined with restriction of domestic stock grazing encouraged dense understorey recovery which reduced the abundance of *Brunonia* in those areas.

- larger clumps survived moderate levels of logging disturbance (e.g. snig tracks), and often increased in numbers, but smaller patches were more likely to be out-competed by more aggressive understorey species.
- *Brunonia* in unlogged quadrats increased in numbers and frequency of subplots occupied, suggesting that understorey thickening was not as prolific as in logged areas despite removal of grazing stock, and unlike logged treatments, more individuals were able to establish (or old plants resprout) in areas away from the larger clumps.
- flowering was significantly greater in logged areas compared to control areas over a 3 year period following disturbance.
- removal of grazing stock to permit adequate overstorey regeneration, is possibly the biggest threat to understorey diversity in logged grassy sites due to competition from more aggressive perennial species, including various weed species.

In this study, a heavy and extensive scarification provided the best opportunity for eucalypt regeneration but caused the biggest impact on *Brunonia* (and many other native understorey species). The impacts of scarification on *Brunonia* may be moderated through careful location of disturbance strips and lower coverage of the treatment but exploring other techniques may provide a better solution. Use of an excavator for scarification is more expensive than a bulldozer but would allow better control on the level of disturbance both in overall coverage and depth of ripping. A better balance of minimizing *Brunonia* destruction but maximizing seedbed opportunities for eucalypt establishment may be achieved through a modification of the excavator heaping technique discussed by Neyland (2000). Low to moderate soil disturbance had limited impact on *Brunonia* numbers but heavy slash piles and undisturbed areas dominated by bracken or thick grass were the main reasons for poorer seedbed conditions for eucalypt regeneration. With excavator heaping, heavy slash piles could be congregated into fewer piles away from retained trees, and known dense patches of *Brunonia*, and subsequently burnt during safe periods. Patches of dense bracken and grass are unlikely to contain the best clumps of *Brunonia* or other native herbs and could be targeted for a light scarification with the excavator. Additionally, some felled tree crowns that do not form a dense mat of slash, may be strategically placed on disturbed areas (and not burnt) to provide a caging effect

for the protection of eucalypt regeneration from browsing (Orr 1991). While this may not counter the problems of future increased understorey competition it would assist improved eucalypt establishment and reduce the direct impacts on *Brunonia* caused by bulldozer scarification.

Another dilemma identified in this study was the problem of dense understorey recovery, particularly of grasses, which was assisted by canopy reduction and ground disturbance, and the need to remove domestic grazing stock for the protection of eucalypt regeneration. Similar effects were observed in other logged forests containing *Brunonia* populations. Successful eucalypt regeneration requires a period of minimal disturbance from factors such as grazing or burning. Reduction of understorey biomass to assist maintenance of native herb and forb populations, therefore, cannot be effectively achieved for several years until the eucalypts attain a height that will avoid damage. The challenge is to maximize seedbed opportunities for eucalypt regeneration and promote fast eucalypt regeneration while limiting both the level of heavy disturbance that destroys *Brunonia* individuals and the amount of dense understorey recovery.

*Brunonia*'s above ground parts senesce over winter allowing a period for other perennial species to take advantage of the available space. The ability of *Brunonia* to resprout from underground vegetative parts following many years (5+) of heavy competition is unknown but is likely to be poor. Succulent *Brunonia* roots were observed on otherwise dead looking plants in heavy grass during its main growing period in late 2001 (3 summers following logging). The small size of these roots and lack of tuberous swellings suggest that their survival for more than another year or two, without resprouting, would be limited. Depending on native browsing pressure, at least 5 years, and possibly as many as 10 years, may be required for eucalypts in dry forests to regenerate to a height that will avoid browsing by sheep (McCormick 1991, Orr and Todd 1992). This is the maximum period recommended by Duffey *et al.* (1974) for rotational winter grazing of grassland areas where maintenance of species diversity is desired. While individuals are likely to live longer, in typical natural conditions, than the 3 years reported by Bodkin (1990) for cultivated plants, 5-10 years without effective resprouting is likely to be too long for *Brunonia*.

For larger populations enough individuals may persist in micro-sites where grass or other competing species do not take over in the 5-10 year eucalypt regeneration period. Subsequent heavy grazing in autumn/winter for 2-3 years and ongoing moderate autumn/winter grazing may allow *Brunonia* to slowly re-establish itself at the site through both vegetative growth and seed dispersal. While plant numbers were reduced at the Bracknell site enough micro-sites remained to allow an approximate distribution reflecting the pre-logging condition. The risk is that such micro-sites will be limited across a logging coupe.

Other logged and scarified populations at Blackwood Creek (nth) and Westwood displayed similar trends to the Bracknell study area. Both areas were consistently covered with dense grass up to 50cm high, 2 years after logging and treatment. Small patches of *Brunonia* could be seen amongst the grass but their potential for survival for more than another year or two was unlikely. The consistent grass cover on these sites suggests a probable severe contraction of the *Brunonia* population but longer-term studies are required to confirm this hypothesis.

To reduce the impacts of dense understorey growth on *Brunonia* abundance (and other natives) following logging on more fertile sites, it is important to either optimize the growth of eucalypt regeneration to allow sooner reintroduction of grazing animals (or fire) and/or minimize the understorey thickening through modified logging. Optimising eucalypt growth would be largely achieved through early establishment of regeneration and subsequent protection from browsing (McCormick 1991). Early establishment is highly dependent on suitable weather conditions (rainfall) but can be influenced through application of proposed silvicultural works as soon as possible after logging. Manual seed sowing would assist early establishment of eucalypts. Use of felled crowns for caging may reduce grazing impacts to some degree as discussed above, but ideally some form of game control should be employed. In one grassy *E. amygdalina* site in Blackwood Creek (sth) that contained *Brunonia*, (annual rainfall 1000mm), eucalypt regeneration was sufficiently established to allow sheep reintroduction in less than 4 years following logging. The area is known to contain high brush-tailed possum and macropod populations but it is presumed that game control through 1080 poisoning in an adjacent plantation area of about the same age, also permitted rapid eucalypt



development in the native forest. Such a time frame may be short enough to allow autumn/winter grazing by domestic stock back on the site soon enough to assist *Brunonia* recovery.

Modified logging may include retention of higher basal areas (e.g. 20m<sup>2</sup>/ha +) or regular and increased retention of undisturbed habitat clumps. Observations during this study suggested that a retained clump of 40 metres diameter is sufficient to limit understorey thickening despite grazing restriction. Retention of habitat clumps at a minimum of 1 per 5 hectares (every 200metres) is required under the Forest Practices Act (2000), in most logging coupes, and the best patches of *Brunonia* could be incorporated in them. The use of 40m+ diameter habitat clumps is recommended for small populations where the risk of local extinction is higher from logging disturbance.

On lower fertility sites, where understorey closure is unlikely to occur, no special prescriptions are recommended other than habitat clumps for small populations and avoiding major disturbances such as roads and landings on the best patches.

#### **7.4 Success of treatments on eucalypt regeneration**

A brief examination of the success of eucalypt regeneration following the silvicultural treatments applied in this study found:

- pre-logging advance growth was very limited and consisted of sporadic *E. amygdalina* lignotubers <1.5m high.
- selective logging followed by mechanical scarification was the most successful method for eucalypt regeneration.
- logging-only provided poor eucalypt regeneration.
- *E. viminalis*, despite comprising 10% of the overstorey, regenerated very poorly. Potential reasons include poorer natural seed crop and possible preferential grazing by native animals but additional research is required.
- growth rate of the regeneration was slow and may take up to 10 years to effectively avoid grazing pressure.

## 7.5 Summary of management recommendations

The factors affecting plant dynamics in remnant dry eucalypt forests and woodlands in Tasmania are complex and there is no single management model that should be imposed upon them (Clarke 2000, Kirkpatrick and Gilfedder 2000). It is, therefore, difficult to recommend precise disturbance regimes for optimum maintenance of *Brunonia* populations across its range in Tasmania. Some general principles however, can be applied and are summarized in table 7.1. For sites currently in good condition (low weed cover, good native species diversity) the best management is likely to be continuation of historical management regimes (Lunt 1997). Carefully applied autumn/winter grazing regimes are likely to be the best option in remnant grassy forests of moderate or higher fertility (most populations). No grazing and only occasional fire is recommended on lower fertility sites where the understorey is sparse and shrubs or heaths are not expected to take over (Kirkpatrick 1999). In areas where domestic grazing stock would be inappropriate due to land tenure, occasional autumn fire or slashing will be essential to maintain suitable open habitat for *Brunonia* if shrubs or heaths would otherwise eventually dominate. These areas include the coastal heathy sites near Exeter, Beaconsfield and Frankford, the shrubby Henry Somerset Orchid Reserve, and other reserves around Launceston (e.g. Carr Villa, Kate Reed, Punchbowl, Brushy Rivulet). Mowing in autumn or winter may be the best option for some smaller populations (e.g. various Launceston Parks).

Determination of the most appropriate management regime for a site containing *Brunonia* is of course also dependent on other important management issues for that area. Other threatened species sensitive to grazing may occur on the site or eucalypt regeneration may be desired but would be compromised, at least during the establishment phase, by any form of ongoing disturbance (Kirkpatrick 1999). Education of landowners is also important as the majority of populations occur on private property. Conservation covenants and management agreements have been implemented for some properties under various Government programs including the Private Forest Reserve Program and Land for Wildlife. It is important that governments continue to investigate better ways of providing incentives for landowners to manage dry forest remnants in Tasmania for their ecological values.

**Table 7.1:** Summary of preferred management options for the maintenance of *Brunonia australis* populations by understorey structure and site productivity. (NB this does not take into consideration other potentially important management considerations for a site including other threatened species)

Management Option	Lower Fertility Sites		Higher Fertility Sites	
	Naturally open understorey	Dense heathy understorey	Grass/herb understorey	Shrubby understorey
<b>1. Private property / active management</b>				
Grazing	restrict or autumn/winter	restrict or autumn/winter	regular autumn- winter grazing	regular heavy autumn- winter grazing
Logging	<ul style="list-style-type: none"> <li>selective (BA&gt;8)</li> <li>sow eucalypts in disturbed areas</li> <li>protect small populations of <i>Brunonia</i></li> </ul>	<ul style="list-style-type: none"> <li>selective (BA&gt;8)</li> <li>burn slash and sow eucalypts</li> </ul>	<ul style="list-style-type: none"> <li>selective (BA&gt;8)</li> <li>expanded habitat clumps over good patches of <i>B.a.</i></li> <li>avoid heavy disturbance on small populations (e.g landings)</li> <li>low intensity excavator heaping, low coverage top disposal burn, or no additional seed bed preparation if adequate ground disturbance</li> <li>early sowing of eucalypts</li> <li>resume winter grazing at earliest opportunity</li> </ul>	<ul style="list-style-type: none"> <li>selective (BA&gt;8)</li> <li>avoid heavy disturbance on small populations (e.g landings)</li> <li>broad coverage excavator heaping or top disposal burn</li> <li>sow with eucalypts</li> <li>resume winter grazing at earliest opportunity</li> </ul>
Burning	low frequency	occasional low intensity fire 5+yrs	restrict if also conducting grazing or low intensity autumn burn every 2-4 years	increase frequency of low intensity autumn burns
<b>2. Reserves</b>				
Bush reserves	low frequency fire	occasional low intensity fire 5+yrs	consider some occasional winter sheep grazing (preserve historical management if healthy population) or high frequency, low intensity autumn burns	consider manual reduction of shrub layer in population vicinity then regular autumn burns or slashing
Small city parks	no action (weed control)	annual autumn-winter slashing	annual winter slashing	once-off reduction of shrub layer then annual/biennial winter slashing
<b>3. Weed Control</b>	Seek specialist advice depending on the species present, density and other site factors			

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## 8. References

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